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ON CERTAIN IMPROVED PHOTOMETRIC APPARATUS AND THE RESULTS THEREWITH OBTAINED.

Stanford University SEP 1 1902

A THESIS

Submitted to the Faculty of Cornell University for the degree of Doctor of Philosophy

by

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ON CERTAIN IMPROVED PHOTOMETRIC APPARATUS AND THE RESULTS THEREWITH OBTAINED.

The material in the following pages, while bearing as a whole upon the general subject of arc-light photometry, has been taken up under four distinct headings, of follows:

I. A DEVICE FOR RECORDING PHOTOMETER SETTINGS.

This device in one form or another has been used throughout all the experimental work of which description is given hereafter.

II. THE DOUBLE MIRROR METHOD AND ITS APPLICATION TO THE STUDY OF COMMERCIAL FORMS OF THE INCLOSED ARC-LAMP.

Following a description of the method and certain measurements to determine its relative accuracy, will be found the experimental results under four sub-headings, namely:

1. The relative value of different makes of the constant potential, direct current, inclosed-arc lamp.
2. The relative value of different makes of the constant potential, alternating current, inclosed-arc lamp.
3. A report on the relative value of direct and alternating current lamps.
4. An investigation of the coating on the inner globes of inclosed-arc lamps.

III. AN IMPROVED APPARATUS FOR ARC LIGHT PHOTOMETRY.

IV. THE LIFE AND EFFICIENCY OF COMMERCIAL-BRANDS OF CARBONS FOR INCLOSED-ARCS.

In this part the apparatus described in part III has been used.

PART I.

A DEVICE FOR RECORDING PHOTOMETER SETTINGS.

A Device for Recording Photometer Settings.

By Charles P. Matthews.

In the ordinary photometric process, there occurs between successive settings a considerable interval, in which a reading of the bar is taken and recorded, either by the observer or an assistant. Various expedients for reading the bar are resorted to, as, for example, the use of a hand-mirror to reflect a beam of light from one of the sources, or the turning on of a glow-lamp. These methods are not free from objection. The sudden influx of light produces in the observer fatigue of the retina and of the pupillary muscles, and there is a consequent loss of visual sensitiveness. Furthermore, when it is a question of the photometry of a fluctuating source, the infrequency and irregularity of the readings is a drawback. In arc-light photometry the illumination of the photometer disk is a shifting quantity. Some means of recording a setting as soon

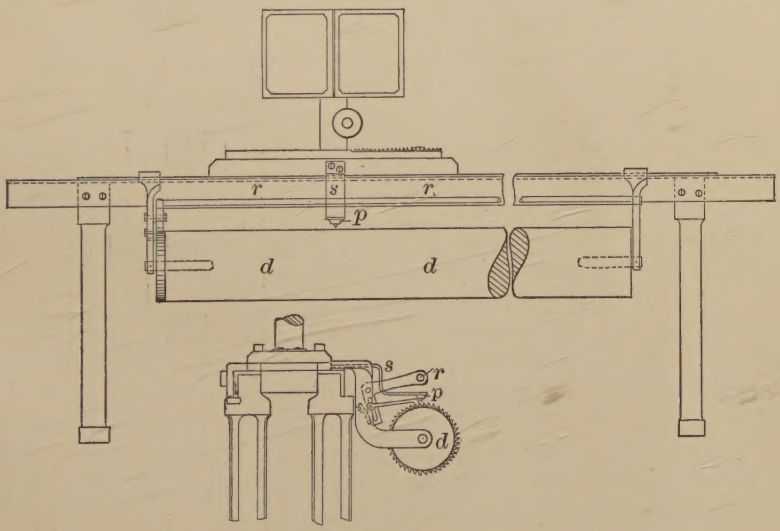

Fig. 1.

as made, thus allowing the observer to proceed to a subsequent setting without interruption or the necessity of removing his gaze from the photometer screen, would seem likely to yield more satisfactory results, with a considerable economy in time.

In the course of experiments on the alternating arc the writer has used a recording drum of the type shown in Fig. 1. A cylinder of wood 10 cm. in diameter and about 1.5 m. in length is mounted with its axis parallel to and somewhat below the top of the photometer bar. At the end of a spring *s*, attached to the photometer carriage, a steel point projects downward nearly to the surface of the cylinder. A rod *r* extends the length of the cylinder and carries at one end a pawl which engages the teeth of a ratchet wheel at the cylinder end. The act of depressing sharply the rod *r* advances the cylinder a certain angular amount and punctures the paper by means of the steel point *p*.

For identifying the records two methods suggest themselves. The point *p* may, at the close of the measurements, be placed over each puncture successively and the corresponding reading taken from the bar, or the paper covering the cylinder may be ruled and marked in the same manner as the bar itself, when the settings may be read directly from the paper. This latter has the advantage of making a permanent record. It is not necessary to have the cylinder of a length greater than $\frac{1}{2}$ to $\frac{3}{5}$ the length of the bar. When mounted on the bar in the manner shown it can be moved so as to accommodate a widely fluctuating series of readings. If it is desired to refer the readings to time, a battery circuit may be arranged so that contact between the rod *r* and the spring *s* will give a bell signal. Two additional observers are then necessary; one to call and one to record time. For a single observer to take readings referred to time the drum must be turned at a known rate by means of a clockwork. This is not a difficult matter to arrange. When it is desired to make a large number of settings without regard to their sequence, the device may be used with the pawl lifted. If two impressions of the point are superimposed the appearance of the puncture usually reveals the fact.

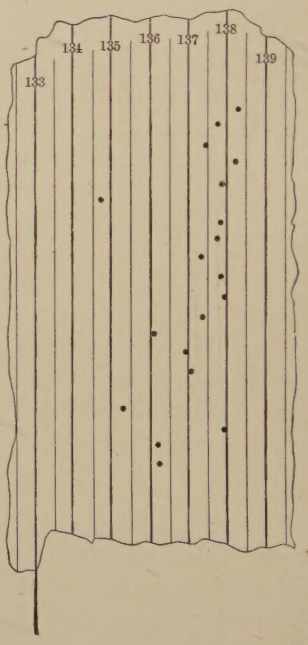

Fig. 2.

The records obtained possess the natural advantages peculiar to graphical results. The apparatus lends itself admirably to the study of personal error, as any peculiarities are at once manifest, while the observer's ignorance of his settings precludes bias. Some interesting personal records have been obtained and will be included in a later report. Fig. 2 is a record of 20 settings on two

glow lamps placed at opposite ends of the bar and connected in parallel. Some retinal fatigue is shown in the increasing divergence of the settings. Comparing these settings with 20 settings made on the same sources but in the usual way we find:

Probable error of mean without recording device = .173
" " " " with " " = .157

These preliminary results indicate a difference of about 10 % in favor of the mechanical recorder.

The writer has successfully used this device in the study of the alternating arc. The well-known feature of the arc known as "hunting" produces great changes in its luminous intensity. While the photometer is peculiarly an instrument requiring deliberate use, one can nevertheless make fairly accurate sittings with sufficient rapidity to include all the major fluctuations in this light source. This point is illustrated in Fig. 3.

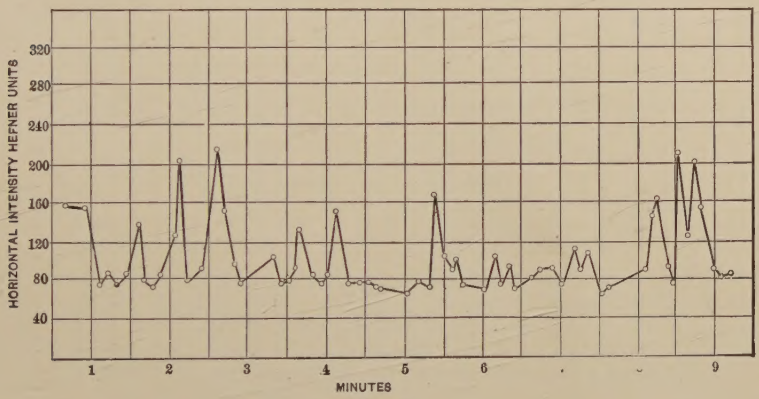

Fig. 3.

The readings occur, on an average, about once in 10 seconds. A Krüss-Bunsen photometer was used, the observer standing well back from the screen. It would doubtless be difficult, if not impossible, to use the Lummer-Brodhun or any other monocular instrument in this way.

ELECTRICAL LABORATORY, PURDUE UNIVERSITY, June, 1898.

PART II.

THE DOUBLE MIRROR METHOD IN ARC-LIGHT PHOTOMETRY AND ITS APPLICATION TO THE STUDY OF COMMERCIAL FORMS OF THE INCLOSED ARC LAMP.

In a paper heretofore published,* I have summarized the causes of error and uncertainty in

*Trans A. I. E. E. XV:599:1898.

arc-light photometry. As these matters are patent enough to any one that has had experience in such work, I will not go into a detailed recapitulation of them here, except in so far as a description of certain methods and devices intended to minimize such errors and uncertainties may seem to necessitate. If one compares the results obtained by different investigators on the luminous intensity of the arc,

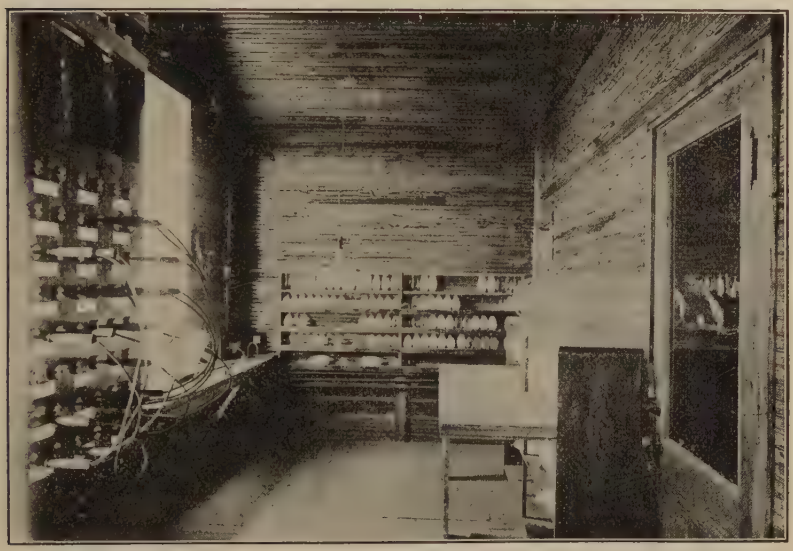

FIG. 4.—PHOTOMETRIC LABORATORY, ADJUSTMENT ROOM.

he finds large discrepancies. Indeed, so discordant are the results that the opinion has been advanced by some that such measurements are almost worthless, and that any attempt to obtain consistent and reliable data on the luminous intensity of the arc might well be abandoned at the outset. This is undoubtedly an extreme view, and, personally, I do not share it. We have to consider the question:

With what degree of accuracy shall we be content? Anything comparable with the accuracy to be obtained in purely electrical measurements is not to be thought of. On the other hand, that the results from different tests should be concordant to a degree no better than fifty per cent would seem to indicate either that such tests have been made under

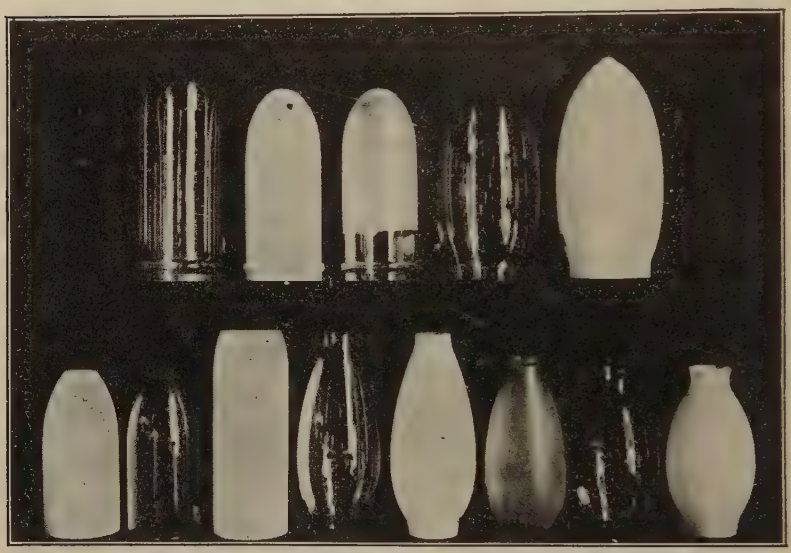

FIG. 5. - TYPES OF INNER GLOBES.

widely different conditions—that is to say, as to carbons, globes, etc.—or that sufficient time and study have not been bestowed on the methods employed. I am of the opinion that an absolute accuracy of less than ten per cent and a relative accuracy in any one series of tests of less than five per cent are quite within the range of possibility.

It is apparent that the difficulties met in the pur-

suit of good results in arc-light photometry may be classified under two heads:

First—Those peculiar to the source, and,

Second—Those peculiar to the method.

Of the first class, none is more troublesome than the great change in the intensity in any given direction, due to the wandering of the arc over the surface of the carbon tips. For instance, if the arc shifts suddenly from the remote side of the carbons to the side towards the photometer, the resulting change in luminous intensity may be 200 per cent. Under these circumstances, the only hope of getting a value representing the mean intensity, at least with the use of one photometer arranged in the ordinary way, lies in taking a relatively great number of readings referred to time, and in integrating the result.

To accomplish this, I have employed, and described elsewhere,* a device to record the settings mechanically. While this is a labor-saving device, it does not obviate the necessity of taking many settings, nor lessen the number of computations. Since taking up the work for your committee, I have constructed a piece of apparatus that greatly reduces the fluctuation in the illumination on the photometer disc, and hence gives a good result with a greatly diminished number of settings. The method involved may be well designated as the *double-mirror method*, and is, so far as I know, new.† It consists in nothing more than the employment of two mirrors instead of one, and in taking light simultaneously from opposite sides of the arc at the same inclination to the vertical, both mirrors being

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* *Physical Review*, November, 1898.

† Since writing this, I find that the eminent French photometrist, Blondel, has embodied a similar principle in his admirable Photomésomètre.
C. P. M.

capable of ready adjustment at any angle in the vertical plane. The arrangement of apparatus for carrying out this plan is shown, somewhat diagrammatically, in Figure 6.

The two mirrors, M, M′, are mounted at the extremities of iron arms, and are suitably counterbalanced, as shown. The arc is fixed in the center of rotation at (a), and light is incident upon the photometer disc at (c), by the two paths shown in dotted lines, direct light from the arc being cut out by a screen not shown in the figure. This plan necessitates a fixed photometer, P, and, in order that a variable illumination may be produced to balance that due to the arc, I have arranged a cord and windlass, W, permitting the observer to move with facility the secondary standard, S, which is a glow lamp.

At D is shown a long wooden cylinder, upon which is wrapped the paper to receive the records of the test. These records are made by an electromagnetic device, R, which punctures the paper whenever an electric circuit is closed at the button, B.

The observer, seated before the photometer in a closely screened inclosure, operating with one hand the windlass, and with the other the push-button, is enabled to take settings with relatively great rapidity and accuracy. At a point 200 cm. to the right of the photometer disc, a reserve standard is mounted on an arm that may be swung into a position in line with the bar. This reserve standard was carefully evaluated once for all in terms of the Hefner lamp. To determine the intensity of the secondary standard, S, it is only necessary to turn the reserve into position and record a series of readings in the same way as for the arc. This operation is carried out at the end of each test, or more frequently if any

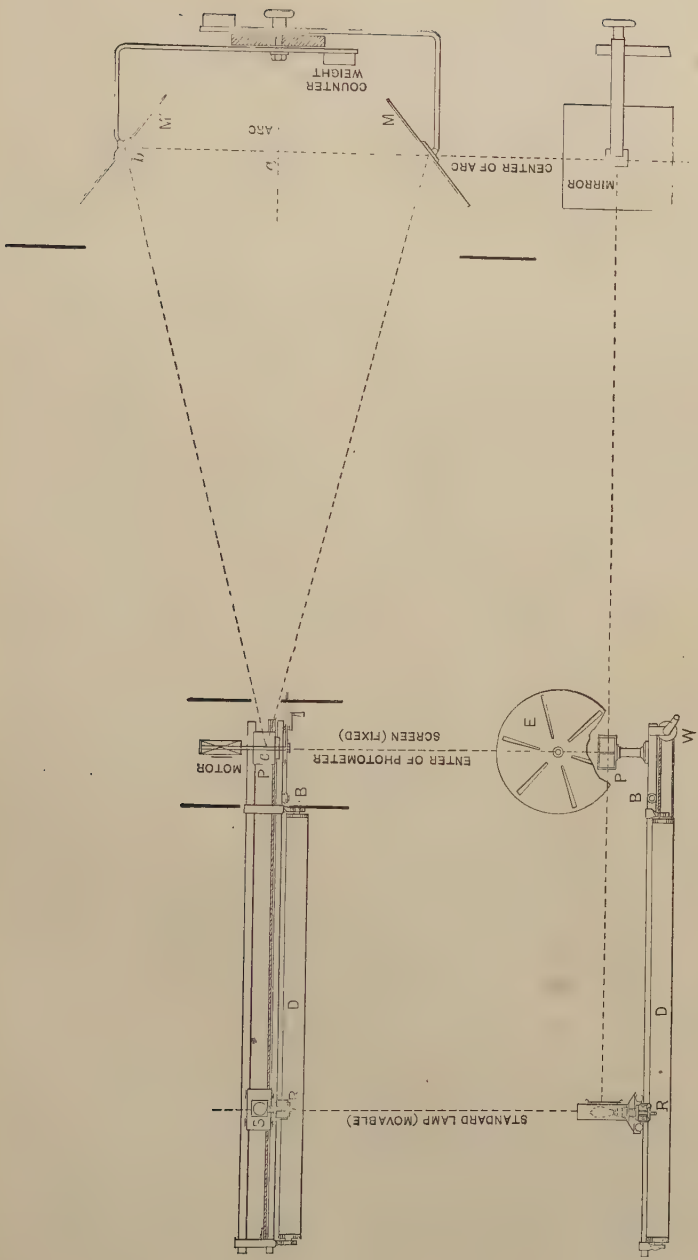

FIG. 6.—APPARATUS FOR THE MEASUREMENT OF LUMINOUS INTENSITY.

change has been made in the temporary standard. Thus, it will be seen that, should the lamp under test be found particularly weak at certain angles, the limit of the bar might be reached in the attempt to get a setting. In such case, it is necessary to stop down the temporary standard and to again refer it to the reserve. I may add that the reserve is never allowed to burn more than a few minutes, and can not possibly deteriorate under such conditions of use.

With this disposition of the mirrors, the angle of incidence at the photometer disc is constant. In Figure 6, this angle is shown at more than twice its actual value, in order to reduce the length of the drawing. The real value of this angle is 5 degrees 54 minutes. To make a correction for this lack of normal incidence would mean the division of the intensities, as found, by the cosine of 5 degrees 54 minutes, or .9947. Failure to do this introduces an error of about one-half of one per cent, which is clearly negligible in work of this character.

If, at a given instant, I′ be the intensity of the arc to the left, and I″ the intensity to the right, d the fixed distance, abc, d_s the distance of the movable standard and K the mirror coefficient, we have as the mean intensity,

$$I = \frac{I + I'}{2} = \left[\frac{d^2}{2d_s^2}\right] \times \frac{I_s}{K}$$

The factor in the bracket was computed once for all for values of d_s throughout the range of the bar, and these values were laid off as graduations on a long T-square. To work out the intensities in any particular test, it suffices to pin the record from the drum upon a long table, and to read directly from a

T-square the values of the bracketed expression corresponding to the punctures in the paper. The mean of these values for any one position multiplied by the factor to the right of the bracket gives the intensity for that position in Hefner units.

It is of course, necessary in testing sources with large globes or shades to use mirrors of such size that the globe or shade may be seen in its entirety, when the eye is placed at the point c (Figure 6); and it is further necessary that the distance *abc* should be large.

It is important to note that the double-mirror method, while enormously diminishing the fluctuation due to wandering of the arc, can have no effect on such fluctuations as are due to variations in length of the arc, or to variations in the current strength. The relative accuracy of the single and double-mirror methods will be brought out in certain data to be found further on.

Of the difficulties peculiar to the method, the most serious arises from the attempt to compare the arc with a standard of different color. It is well known that when the color difference is marked the setting partakes of the nature of a guess, differing not only with different observers, but with the same observer at different times. To minimize the error due to this cause, I have made use of the physiological fact that, as the illumination of two surfaces tends toward zero, the eye appreciates their difference in color to a less and less degree, and is thus able to estimate an equality in luminosity unhampered by the sensation of color. Thus, the method of winking, or half-closing the eyes, has been used by many experimenters to diminish the color sensation. These latter processes are very fatiguing to the observer, and

I have adopted the plan of diminishing the intensity of the photometric field by the use of a rotating sectored disc E (Figure 6) of very small angular opening. Ferry has found that the use of the sectored disc to reduce the intensity of *one* source in comparison with another of different color introduces an error, because the ratio of the light transmitted to light cut off does not appear to be the ratio of the open to the closed sectors when the opening is small. It will be noted that the disc in the figure is so placed as to diminish equally both sides of the photometric field, and hence one would not look for an error of this character.

To test the accuracy of these methods with different observers, I operated upon an automatic feed, inclosed arc in exactly the manner that has prevailed throughout the tests, and requested four observers, whom I will designate by S, G, K and F, to make nine settings each. The mean results are:

S	G	K	F
813	808	852	845

These are the light ratios multiplied by a constant. The mean of all is 830. Hence, the individual means differ from the mean of all by:

S	G	K	F
−2%	−2.6%	+ 2.6%	+ 1.8%

As these settings lay in nearly the same range on the recording drum, I inferred that a part of the variation was due to an insufficient number of settings.

Subsequently, observers M and K, who have made all the settings in the arc-light tests that

follow, took a greater number of settings, with the following results:

M (16 settings)	K (14 settings)
770	775

This agreement of 0.7 per cent is so close that I am inclined to regard it as somewhat fortuitous, but one may safely conclude that the error due to the personal equation of the observer is little greater when this method is used than it is in the comparison of sources of like color.

As to the error due to fluctuation, I had previously taken, by the single-mirror method and the recording drum, seventy-one settings in a particular direction. Taking now as a *fluctuation factor the mean deviation from mean* of these seventy-one settings, and disregarding signs, one obtains

Mean intensity × a constant	=92.9
Fluctuation factor	=29.6= 32 per cent.
Maximum deviation	=99 =106 "

With the double-mirror method the mean of the thirty values obtained by K and M gives:

Mean intensity × a constant	=772
Fluctuation factor	= 69.5= 9 per cent.
Maximum deviation	=268 =34.7 "

or, in a word, the fluctuation with the single-mirror method is more than thrice that with the double-mirror method.

UNITS

The values of luminous intensity in these tests are expressed in terms of the Hefner amylacetate lamp. They may be reduced to British candles by multiplying by the factor .88. I would call attention,

however, to the fact that this is little more than multiplying by an arbitrary constant, since no one knows definitely what the luminous intensity of the British candle is. On the other hand, the Hefner unit has met with an international sanction, and is quite generally accepted as a unit, far from perfect, but possessing, especially for practical purposes, fewer faults than any unit thus far proposed.

SPECIAL TEST

When an opalescent inner globe is used, the globe itself becomes more or less luminous by diffusion. The diffusion differs with the height of the arc in the globe, that is to say, with the length of the lower carbon. To ascertain the magnitude of this effect, I have carried through three tests on the same lamp and inner globe, and also the same carbons, the lower carbons being cut successively to the lengths four and three-quarter, two and three-quarter and one and one-quarter inches. The results appear in Table 1 and Figure 7. In every case the arc was placed at the center of the mirror system.

An inspection of these results shows that least light is obtained with the arc at the top of the globe, and most light when the arc is at the mid-point. This is explained in part by the fact that with the arc at the top a good part of the luminous flux is incident upon the non-reflecting surface of the gas cap.

While the second and third positions yield a considerably increased flux of light with a clean globe, they

must be considered as impossible conditions in practice, since, by the time the arc has descended to these points, the globe has received a coating. The net result then, as the lamp burns, is due to an increase in light flux due to the descending arc, and a diminution in light flux due to the formation of a coating. How this affects the quantity of light emitted—

TABLE 1

Special test, showing effect of height of arc in globe

Angle	4¾ inches	2¾ inches	1¼ inches
59° A	61.3	(55A) 88.1	
50 A	129.1	122.2	132.7
40 A	190.6	209.4	149.1
30 A	169.5	214.6	173.5
20 A	215.6	273.5	269.4
10 A	234.0	265.1	247.8
Hor.	215.5	296.3	252.3
10 B	277.8	369.5	372.3
20 B	291.7	423.9	388.5
30 B	382.4	448.0	365.9
40 B	354.6	465.8	435.1
50 B	264.3	402.6	353.3
60 B	263.	329.	278.1
70 B	202.9	243.5	197.3
80 B	3.64	36.9	
Globes	**Opalescent Inner Only**		
Mean hemispherical, upper	178 H. U.	199 H. U.	185 H. U.
Mean hemispherical, lower	288 H. U.	385 H. U.	351 H. U.
Mean spherical	233 H. U.	292 H. U.	268 H. U.

that is, the product of flux and time integrated throughout the life of the carbons—is a subject for future investigation, and involves the questions of carbons, shape of globe, etc.

In the tests that follow, I have chosen the initial condition as the simplest to obtain, even though the light emitted may be less than at some subsequent period in the life of the carbons.

Should any one desire to test a lamp for the purpose of obtaining comparative results, he would not be under the necessity of burning the lamp for many

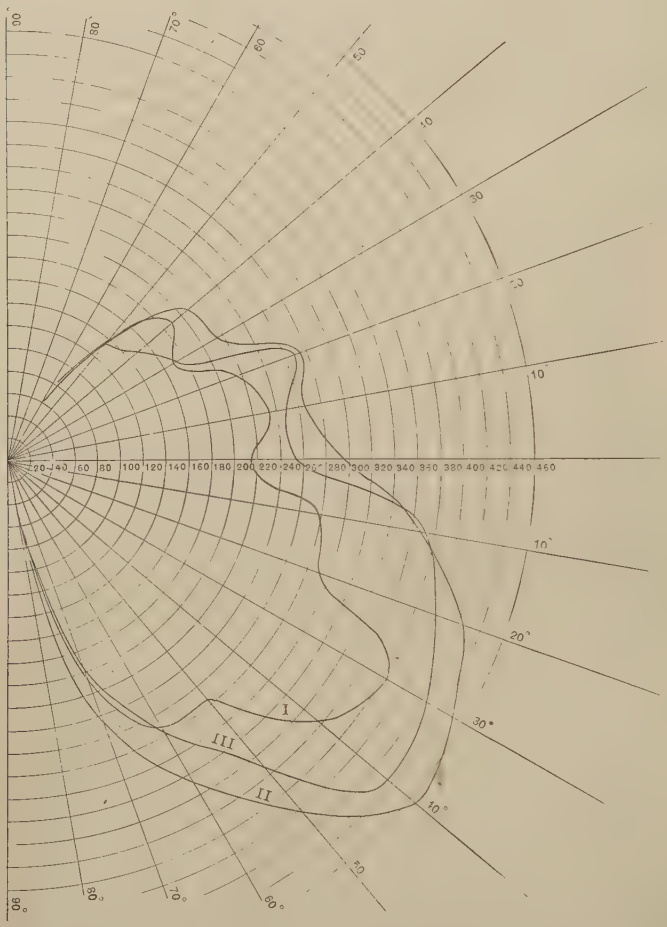

FIG. 7.—VARIATION OF LUMINOUS INTENSITY WITH HEIGHT OF ARC IN A CLEAN OPALESCENT GLOBE.

Curve I.—Lower Carbon, 4¾ in. Curve II.—Lower Carbon, 2¾ in. Curve III.—Lower Carbon, 1¼ in.

hours to get the proper conditions, as he would necessarily have to do were one of the lower positions chosen in these tests.

FIRST INVESTIGATION

In order to determine the status of the direct-current, inclosed arc as found commercially on the market, it seemed desirable to study first the questions of luminous intensity, power consumption and efficiency, taking the lamps as supplied by the makers, but operating under a certain uniformity in conditions. These conditions are

1. The same brand of carbons throughout.

2. An opalescent or milky inner globe, and a clear outer, as supplied.

3. An opalescent inner globe, and an "opal," ground, or milky outer globe, as supplied.

To these, I have added in certain cases a test with no outer globe whatever, in order that the absolute, as well as the relative, absorption of the outer globes might be found.

The lamps are fitted with the proper lengths of carbons, and adjusted, *as nearly as possible*, to the voltage at the arc named in the makers' specifications. They are then allowed to burn until thoroughly heated before the test begins. One observer maintains the terminal electro-motive force constant, and takes readings of the current throughout the test, while another operates the photometer. The values of current given are therefore the mean of many readings.

From the records taken off the recording drum the values in the tables are computed. These values are then plotted in polar co-ordinates, as shown in the curves below, and also in rectangular co-ordinates in the well-known Rousseau diagram, which latter is integrated by the planimeter to get the mean spherical intensity.

In this way eight direct-current, 110-volt lamps have been tested up to the present writing.

Referring to the lamps by number we find the results on Lamp 1 in Table 2, Figure 8.

The curves show very clearly the slight absorption of the clear outer and the large absorption of the opalescent outer. The clear outer globe shows some diffusion, as it tends to round out the curve. Thus

TABLE 2

LAMP 1

Angle	Test 1	Test 2	Test 3
59° A	109.8		
50 A	140.3	35.	(45A) 54.9
40 A	162.6	85.3	87.2
30 A	169.7	137.7	159.5
20 A	178.5	207.9	223.9
10 A	218.1	246.4	270.2
Hor.	190.9	259.	253.2
10 B	178.3	282.1	334.7
20 B	214.67	370.7	400.1
30 B	191.7	401.6	454.3
40 B	188.2	404.3	432.1
50 B	209.3	346.1	387.1
60 B	134.4	308.	307.1
70 B	114.1	177.8	303.3
80 B	175.2	264.7	101.3

Globes	Op Inner Op. Outer	Op. Inner Clear Outer	Op. Inner No Outer
E. M. F.	110 volts	110 volts	110 volts
Current	4.87 amperes	5.07 amperes	5.08 amperes
Watts	535.7	557.7	558.8
Mean hemispherical intensity	Upper, 159.5	137.5	149.9
	Lower, 186.4	332.2	362.4
Mean spherical intensity	172.9	234.8	256.1
Watts per mean H. U.	3.10	2.37	2.18

there are two regions where curve II extends beyond curve III. In the case of the opalescent outer globe, the diffusion is so marked that the luminous intensity is practically constant throughout a very large solid angle. In the higher angles above the horizontal, the intensity is greatly increased, producing the effect, approximately, of a luminous sphere of equal intrinsic

brightness. This results in the elimination of shadows, and the production of a pleasing light for interiors. The quality of light is also changed to a considerable

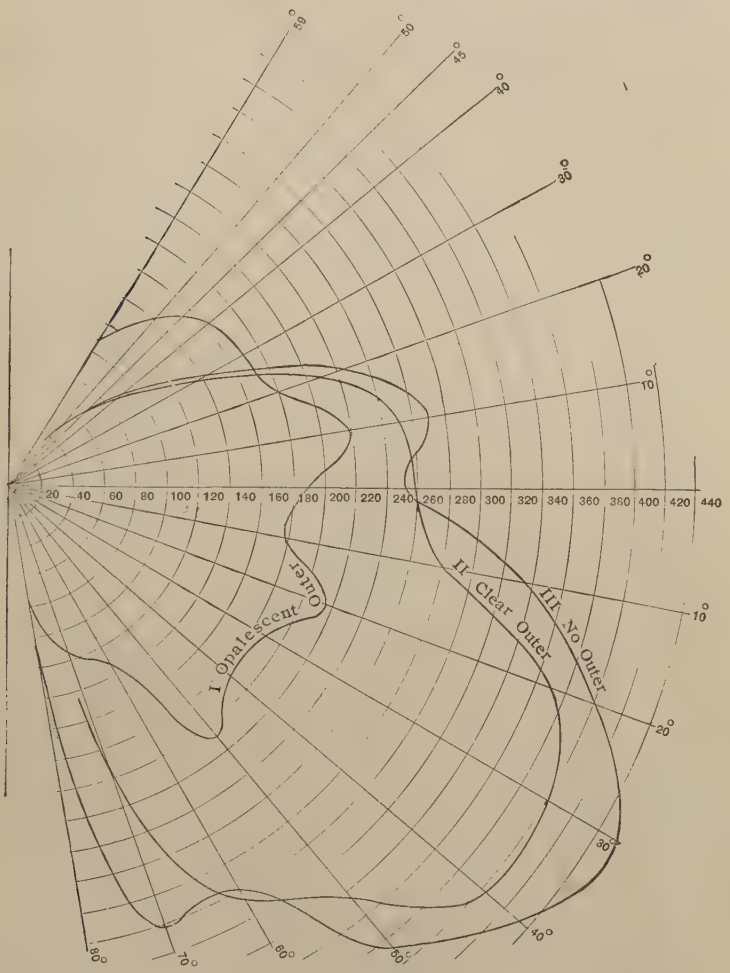

FIG. 8.—LAMP I.

Curve I.—Opalescent Outer Globe. Curve II.—Clear Outer Globe. Curve III.—No Outer Globe.

extent through the absorption of the excess of violet rays otherwise very marked in the light of the arc. This result is attained, however, at a diminished

efficiency. In this and nearly all the curves with the opalescent outer globes, a certain wavy outline is noticed. I think this effect is due, in large part, to the variations in the diffusive power of the globe itself. One finds difference in thickness and translucency to a considerable extent in such globes, and.

TABLE 3

LAMP 3

Angle	Test 1	Test 2
59° A	(55A) 59.5	87.3
50	102.7	114 7
40	153.7	165.3
30	164.2	182.8
20	203.8	198.1
10	209.3	206.2
Hor.	219.8	222.8
10 B	262.7	239.2
20	273.1	232.6
30	328.7	219.1
40	364.1	241.4
50	315.5	282.1
60	224.8	227.
70	288.6	185.7
80	110.2	165.8

Globes	Op. Inner Clear Outer	Op. Inner Op. Outer
E. M. F.	110 volts	110 volts
Current	5.1 amperes	5. amperes
Watts	561.	550.
Mean hemispherical intensity H. U.	Upper, 150.	160.
	Lower, 282.	230.
Mean spherical H. U.	216.	195.
Watts per mean spherical	2.60	2.85

as the angle of view changes, these differences would tend to distort the distribution curve.

In Table 3 and Figure 9 are the results of two tests with the usual combination of globes on lamp 3. In this case the opalescent globe transfers a certain portion of the luminous flux to the upper hemisphere —sufficient, in fact, to throw curve II quite out to the curve obtained with the clear globe.

Following are the data and curves of a test on lamp 4. This lamp is provided with an outer globe of ground glass. The inner globe has straight walls,

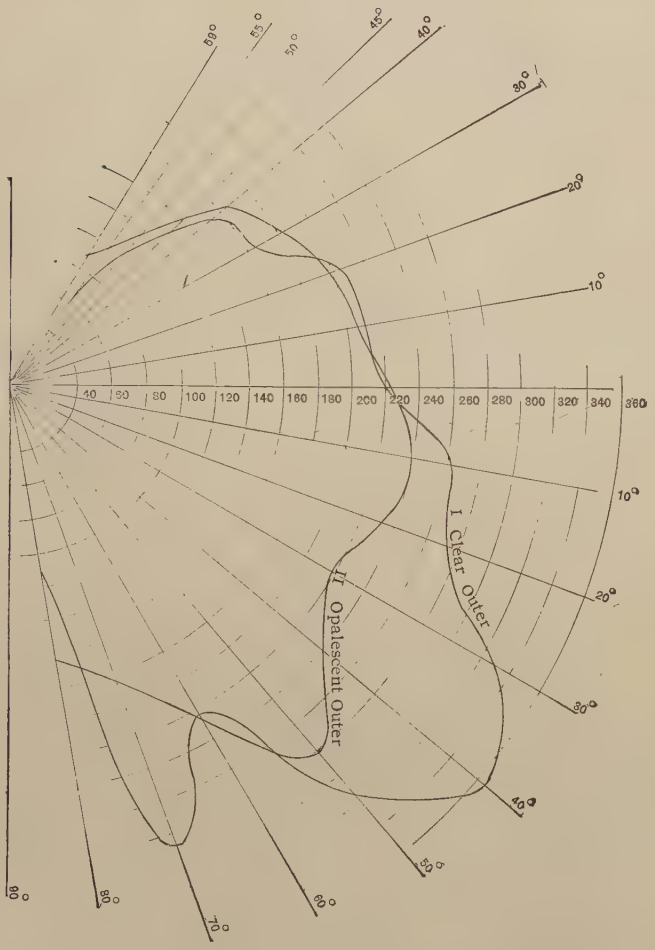

FIG. 9.—LAMP 3.

Curve I.—Opalescent Inner, Clear Outer. Curve II.—Opalescent Inner, Opalescent Outer.

and with the arc at the top the distribution curve comes out somewhat oddly. The luminous flux above the horizon is very small. The strong intensity at eighty degrees below with the clear outer globe

has been found in more than one case under like conditions. I have not been able, thus far, to arrive at a satisfactory explanation of it, but it seems to be associated in some way with a multiple reflection due to the outer globe. Professor Thomas has found similar strong changes in intensity in the case of the

TABLE 4

LAMP 4

Angle	Test 1	Test 2
59° A		
50	39.5	
40	52.6	
30	81.	28.3
20	107.2	80.4
10	136.7	167.6
Hor.	145.2	213.4
10 B	185.5	231.9
20	199.5	235.
30	185.3	219.9
40	199.	208.9
50	140.3	175.8
60	143.4	176.3
70	192.	168.8
80	104.2	190.5

Globes	Op. Inner Ground Outer	Op. Inner Clear Outer
E. M. F.	110 volts	110 volts
Current	4.76 amperes	4.76 amperes
Watts	523.6	523.6
Mean hemispherical intensity in H. U.	Upper, 80.4	70.4
	Lower, 173.6	208.
Mean spherical H. U.	127.	139.2
Watts per mean spherical	4.12	3.76

slow lamp, due to images of the filament, whose effect becomes very marked at certain angles. It may be that we have a similar phenomenon here.

In figures 11, 12, 13, 14 and 15 are found the curves taken on lamps 5, 7, 9, 10 and 12 respectively. The corresponding tables are 5, 6, 7, 8 and 9. These tests are made under the conditions already specified.

The curves differ in detail, but show similar characteristics. In considering them, one should remember that while the lamps have nominally outer globes of

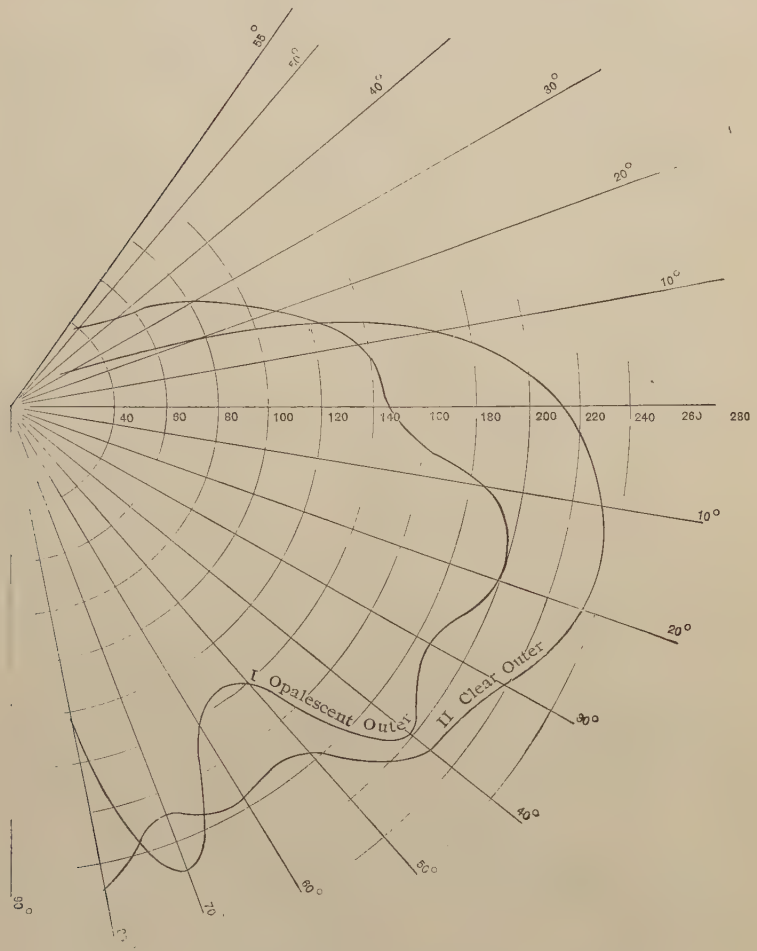

FIG. 10.—LAMP 4.

Curve I.—Ground Outer Globe. Curve II.—Clear Outer Globe.

the same kind, they have markedly different inner globes. Again, some of the lamps have a bright metallic surface above the inner globe. This surface

acts to some extent as a reflector. Taking these facts into consideration in connection with the variations in the transparency of different parts of any one outer globe, one can understand why these curves do not more closely follow a general type.

TABLE 5

LAMP 5

Angle	Test 1	Test 2
59° A	91.9	114.5
50	110.4	140.5
40	114.7	134.9
30	157.9	166.7
20	154.5	163.1
10	162.2	177.6
Hor.	160.0	169.1
10 B	206.4	176.2
20	274.6	165.5
30	256.4	179.5
40	263.8	168.9
50	225.3	162.7
60	212.3	162.7
70	105.2	157.2
80	144.7	157.2

Globes	Op. Inner Clear Outer	Op. Inner Op. Outer
E. M. F.	110 volts	110 volts
Current	4.16 amperes	4.16 amperes
Watts	457.6	457.6
Mean hemispherical intensity in H. U.	Upper, 126.6	141.6
	Lower, 220.8	167.2
Mean spherical H. U.	173.7	154.4
Watts per mean spherical H. U.	2.63	2.96

I will leave further discussion of the curves showing distribution of luminous intensity until the second and third divisions of this subject, as outlined by your committee, have been taken up, and pass to other matters in a résumé of the results of the first investigation. At a common terminal electro-motive force of 110 volts, seven of these lamps take an average current of 4.90 amperes, which means an average total

power consumption in each lamp of 539 watts. With 80 volts at the arc this power is divided into 147

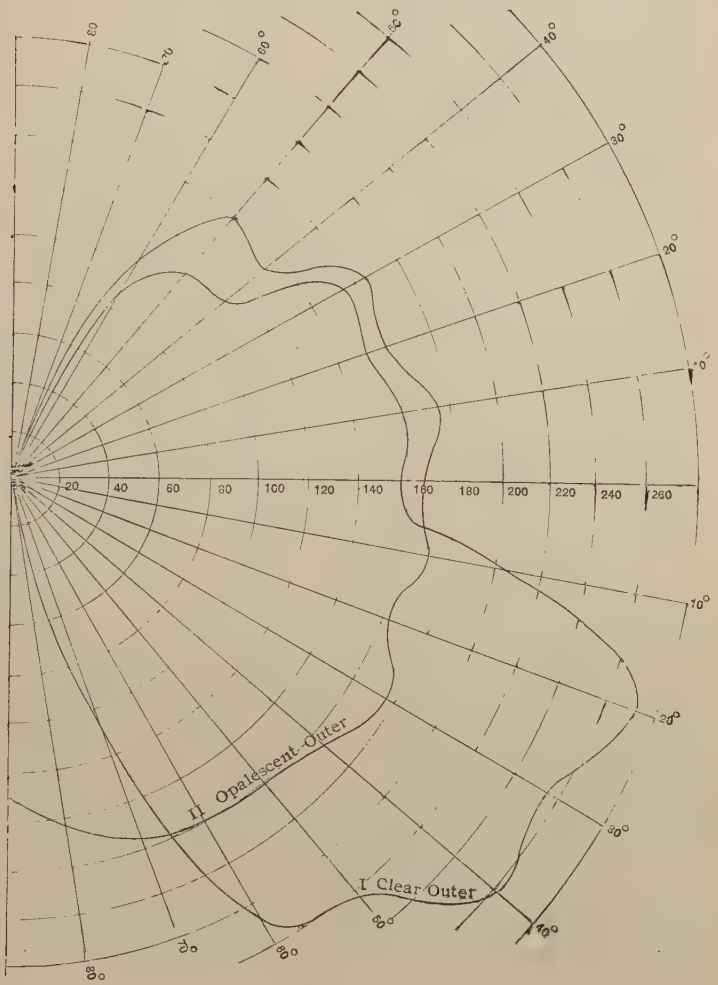

FIG. 11.—LAMP 5.
Curve I.—Clear Outer Globe. Curve II.—Opalescent Outer Globe.

watts waste in the resistance coils and 392 watts in the arc. The average yield of light, expressed as mean spherical intensity, is:

Opalescent inner, no outer* =256 H. U.
" " clear outer =207 H. U.
" " opalescent outer =177 H. U.

TABLE 6

LAMP 7

Angle	Test 1	Test 2	Test 3
60° A			113.7
50	49.9	104.9	145 8
40	65.6	135.2	157.6
30	103.3	164.7	183.7
20	150.2	167.9	194.2
10	135.4	231.7	218.7
Hor.	182.7	256.5	215.1
10 B	191.3	299.2	251.9
20	225.7	313.	242.5
30	237.4	357.6	234.9
40	236.8	407.9	238.6
50	195.6	403.5	234.2
60	173.4	235.	220.6
70	142.3	173.4	193.4
80	63.3	197.9	237.

Globes	Op. Inner Coated. Clear Outer	Op. Inner Clear Outer	Op. Inner Op. Outer.
E. M. F.	110 volts	110 volts	110 volts
Current	4.76 amperes	4.66 amperes	4.87 amperes
Watts	523 6	512.6	535.7
Mean hemispherical intensity, H. U.	Upper, 96.	149.	175.
	Lower, 200.	316.8	232.
Mean spherical, H. U.	148.	232.9	203.5
Watts per mean spherical, H. U.	3.54	2.20	2.63

Hence the power required to produce one unit of light in this type of lamp is

Opalescent inner, no outer* =2.10 watts.
" " clear outer =2.66 watts.
" " opalescent outer =3.04 watts.

*The computations for no outer globe have not the same value as the others, for the reason that the number of such tests was less.

In conclusion, I would call attention to the fact that these figures give the value of this type of lamp

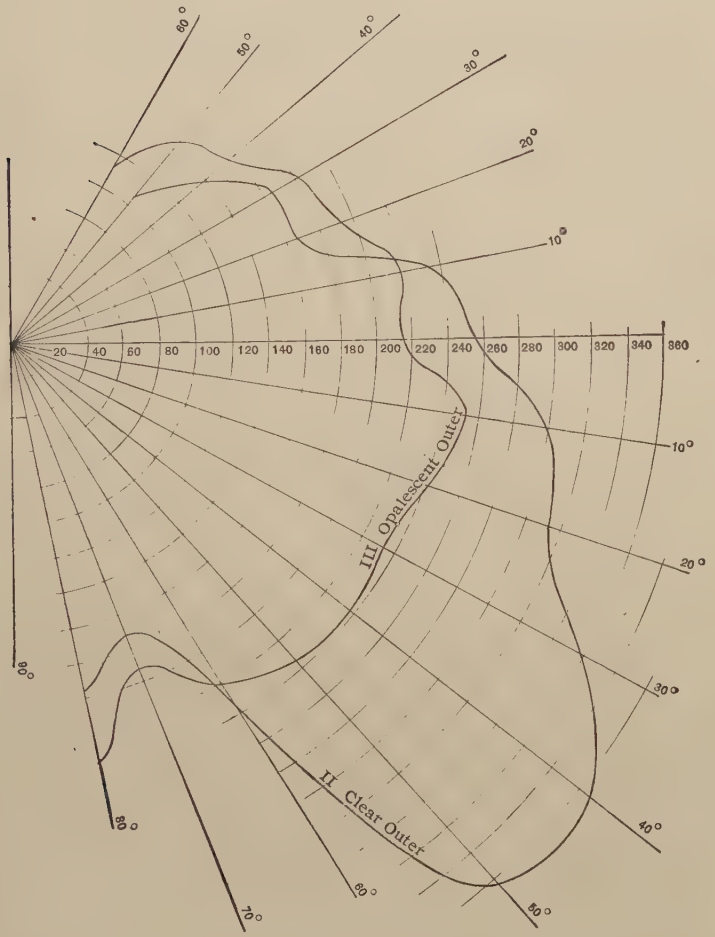

FIG. 12.—LAMP 7.
Curve II.—Clear Outer Globe. Curve III.—Opalescent Outer Globe.

as a *light producer*, and not as a *light distributor*. The efficiency of the type as a distributor of light can best be found from a consideration of the curves

of illumination—a matter that does not form a part of this investigation.

SECOND INVESTIGATION

As furnishing data on the luminous intensity, power consumption and efficiency of the alternating-

TABLE 7

LAMP 9

Angle	Test 1	Test 2
55°A	126.5	91.8
50	153.6	118.0
40	189.1	168.7
30	188.4	184.1
20	211.5	243.5
10	211.3	220.2
Hor.	209.4	247.6
10 B	231.4	323.9
20	206.9	301.6
30	217.0	313.3
40	181.4	294.0
50	158.0	253.5
60	165.5	214.1
70	136.5	254.7
80	156.4	110.

Globes	Op. Inner Op. Outer	Op. Inner Clear Outer
E. M. F.	110 volts	110 volts
Current	4.79 amperes	4.9 amperes
Watts	526.9	539.
Mean hemispherical intensity, H. U.	Upper, 170.4 Lower, 194.4	171.2 281.2
Mean spherical, H. U.	182.4	226.2
Watts per mean spherical H. U.	2.83	2.38

current, inclosed arc lamp for constant-potential circuits, I give below the results of tests on seven lamps. These tests have been carried through under conditions identical with those prevailing in the first investigation. In two cases the lamps were accom-

panied by shades, and these lamps were subjected to additional tests to bring out the advantages of using a shade on an alternating-current lamp.

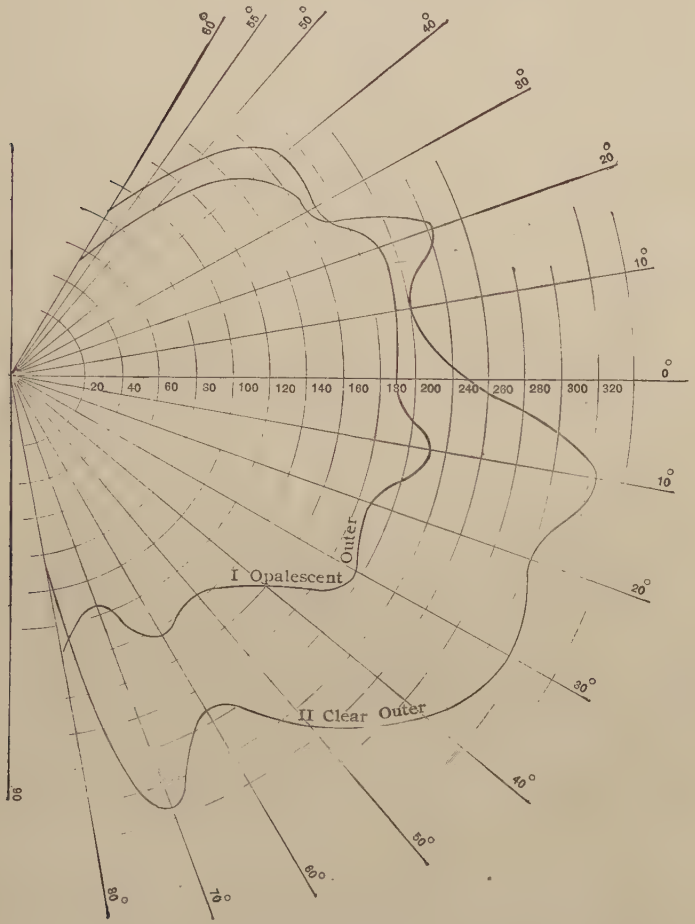

FIG. 13.—LAMP 9.

Curve I.—Opalescent Outer Globe. Curve II.—Clear Outer Globe.

The lamps are adjusted for voltage at the arc, and for the frequency of the supply, which is 60 cycles.

After burning a sufficient time, they are tested in the manner already described.

Since lamps of this type are used with one cored and one solid carbon, some difference in the curve of distribution might be looked for as a result of using

TABLE 8

LAMP 10

Angle	Test 1	Test 2
59°A	(55A) 110.1	
50	125.7	82.7
40	129.7	177.7
30	188.1	198.7
20	219.6	230.
10	264.1	268.2
Hor.	246.8	247.
10 B	239.6	279.7
20	230.7	370.7
30	293.6	399.2
40	244.1	353.5
50	210.7	254.2
60	215.9	277.7
70	135.9	279.2
80	154.	121.5

Globes	Op. Inner Op. Outer	Op. Inner Clear Outer
E. M. F.	110 volts	110 volts
Current	5.05 amperes	4.94 amperes
Watts	555.5	543.4
Mean hemispherical intensity, H. U.	Upper, 173.6	176.
	Lower, 230.8	308.8
Mean spherical H. U.	202.2	242.4
Watts per mean spherical H. U.	2.74	2.24

the cored carbon above and the solid one below, or vice versa. In Table 11 and Figure 16 will be found the results of two tests intended to give information on this point. Lamp 102 was tested under the usual conditions of an opalescent inner and a clear outer globe, the cored carbon being below. Some days

later the lamp was tested with the same globes, but with the carbon pencils interchanged, the upper pencil

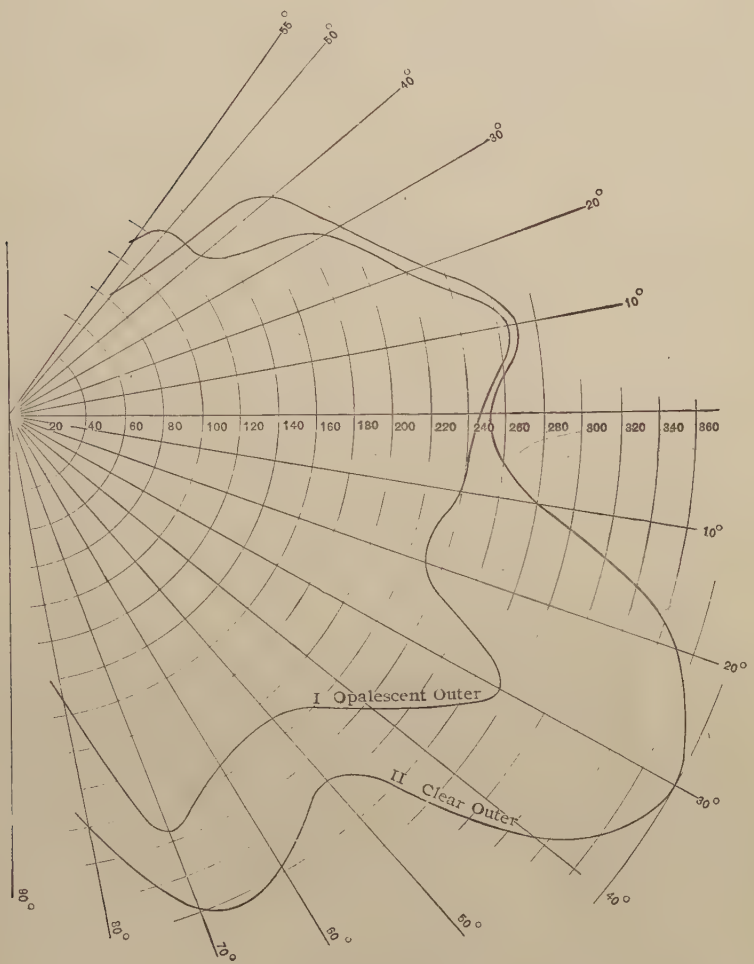

FIG. 14.—LAMP 10.

Curve I.—Opalescent Outer Globe. Curve II.—Clear Outer Globe.

being the cored one. The globe was clean in both cases. It will be noted that the curves follow each

other closely, particularly below the horizontal. The slight variations in the curves neutralize each other so that the mean spherical intensity comes out the same in both cases. It is to be concluded from this test that the reversal of the carbons, which takes place

TABLE 9

LAMP 12

Angle	Test 2	Test 4	Test 5
54° A	116.9		
50	134.8	61.1	78.4
40	169.8	126.9	129.2
30	171.2	211.9	138.4
20	176.4	236.3	154.2
10	190.9	253.0	162.3
Hor.	219.8	239.9	186.1
10 B	228.0	247.8	241.9
20	214.8	282.3	236.3
30	198.3	269.8	208.2
40	189.1	236.7	209.2
50	175.0	195.3	185.1
60	171.9	173.2	151.5
70	137.9	168.4	176.7
80	251.5	84.0	150.3

Globes	Op. Inner Op. Outer	Op. Inner Clear Outer	Op. Inner Coated. Clear Outer
E. M. F.	110 volts	110 volts	110 volts
Current	4.93 amperes	4.73 amperes	4.74 amperes
Watts	542.3	520.3	521.4
Mean hemispherical intensity, H. U. Upper	154.4	160.	120.8
Mean hemispherical intensity, H. U. Lower	200.8	230.4	204.8
Mean spherical H. U.	177.6	195.2	162.8
Watts per mean spherical H. U.	3.05	2.66	3.20

whenever the lamp is newly trimmed, makes but little difference in the total luminous flux from the lamp. However, in the tests reported below, the uniform practice of a cored lower carbon was kept to.

Table 12 and Figure 17 exhibit the results of a test on lamp 101. These might be taken for the

curves from a direct-current lamp, so small is the luminous flux in the upper hemisphere. It must be

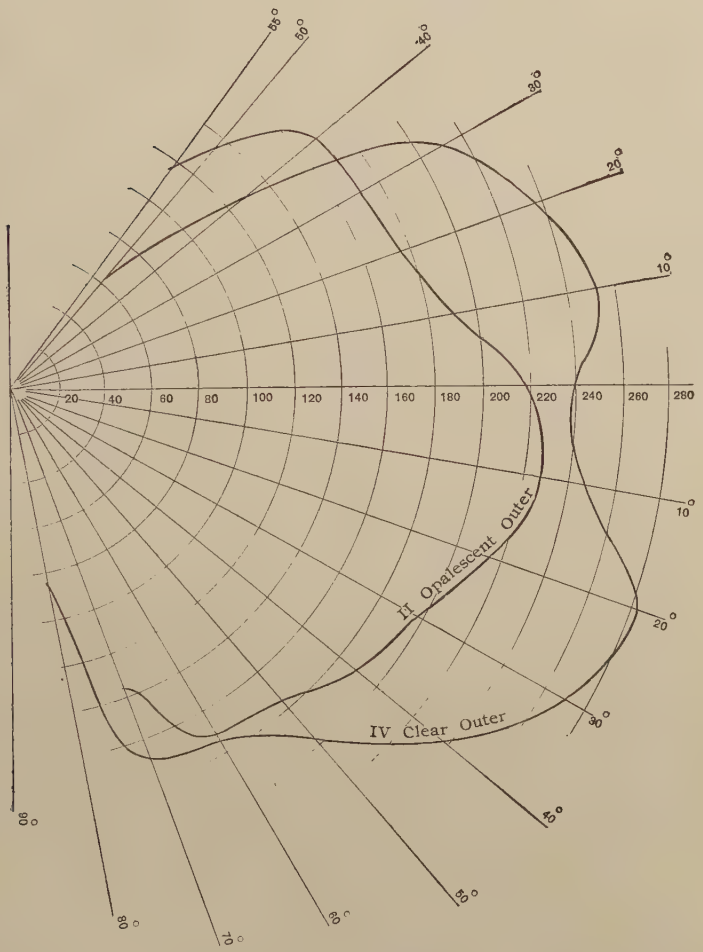

FIG. 15.—LAMP 12.

Curve II.—Opalescent Outer Globe. Curve IV.—Clear Outer Globe.

remembered, however, that the arc is at the top of the globe, as already explained, and much of the upward light is either absorbed or reflected by the

comparatively broad surfaces just above the inner globe.

The maximum intensity is found in its usual position, thirty degrees below. The opalescent outer globe shows the usual diffusive properties.

TABLE 10

LAMP 12

Angle	Test 1	Test 3
54°A	76.9	
50	77.7	72.6
40	123.2	163.0
30	140.9	228.9
20	150.8	259.
10	155.1	276.6
Hor.	169.8	314.1
10 B	165.1	343.9
20	166.7	314.1
30	195.6	300.8
40	167.8	255.3
50	175.9	258.3
60	176.2	207.8
70	210.3	87.3
80	169.6	197.2

Globes	Op. Inner Coated. Clear Outer	Op. Inner Clear Outer
E. M. F.	110 volts	110 volts
Current	4.98 amperes	4.97 amperes
Watts	547.8	546.7
Mean hemispherical intensity, H. U.	Upper, 125.4 Lower, 176.8	185.6 281.2
Mean spherical H. U.	151.1	233.4
Watts per mean spherical H. U.	3.62	2.34

Three tests on lamp 102 have been carried out. The highly beneficial effect of a shade is here well shown. (Figure 18.) With the arc at the top of the globe, the shade in this case received all the upward flux of light and a portion of the downward flux. The result is that the horizontal intensity is

diminished, but below ten degrees B the result of substituting a shade for an outer globe is very

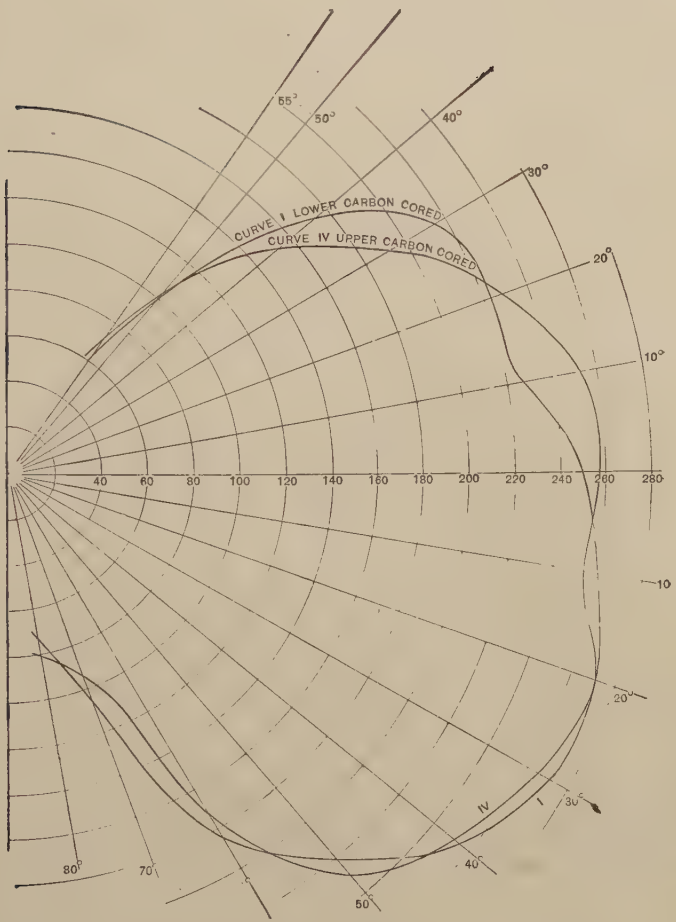

FIG. 16.—LAMP 102.

Curve I.—Clear Outer, Lower Carbon Cored. Curve IV.—Clear Outer, Upper Carbon Cored.

beneficial. In fact, the mean hemispherical intensity with shade bears to that with clear outer globe the

ratio 266 : 236, or an increase of nearly thirteen per cent. Taking a similar ratio with reference to the opalescent outer globe, one finds 266 : 165, or an increase of sixty-one per cent. As the arc burns lower, the intensities between the horizontal and

TABLE 11

Angle	Test 1	Test 4
55°A	66.1	57.3
50	96.1	97.3
40	170.9	152.2
30	215.7	195.3
20	223.6	227.5
10	225.9	252.2
Hor.	249.8	256.0
10 B	259.8	253.3
20	270.4	270.8
30	270.7	265.2
40	256.5	251.9
50	220.8	229.7
60	184.8	174.0
70	106 1	93.8
80	72.6	81.4

Globes	Op. Inner Clear Outer	Op. Inner Clear Outer
E. M. F.	110 volts	110 volts
Current	6.81 amperes	6.80 amperes
App. Watts	749.1	748.
Watts	459.	478.
Power Factor	.61	.63
Mean hemispherical intensity in H. U.	Upper, 169.4 Lower, 236.5	169.4 234.6
Mean spherical in H. U.	202.9	202.
Watts per mean H. U.	2.26	2.36

ten degrees B will naturally be strengthened, because the arc will no longer be eclipsed by the shade. At the same time the intensities in all directions will be increased, for the reasons already discussed in connection with Figure 7. For the illumination of points remote from the arc it is better that the solid

angle subtended by the shade should not exceed 2π steradians, as it does in the case here represented.

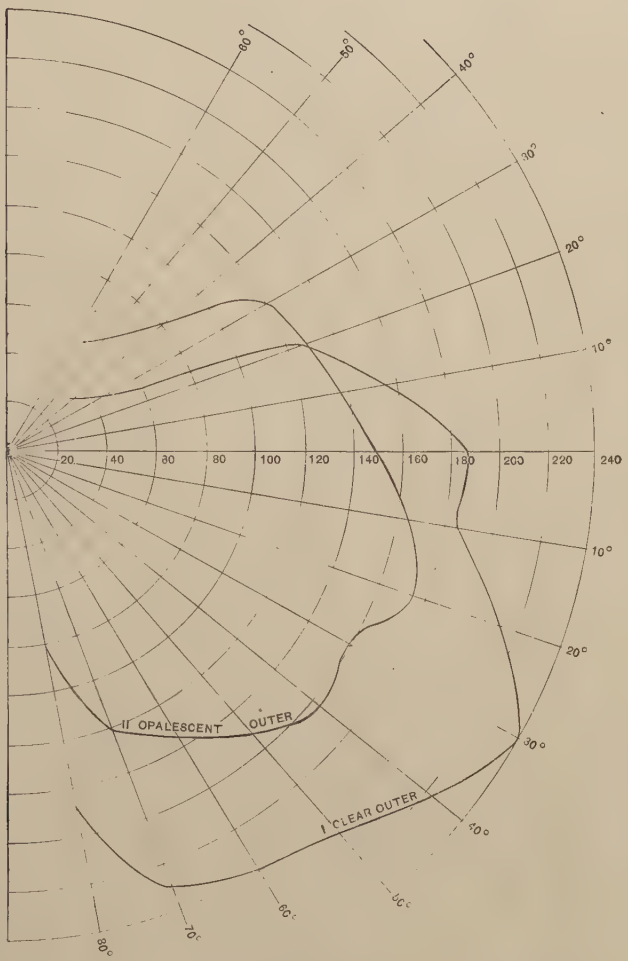

FIG. 17.—LAMP 101.

Curve I.—Clear Outer Globe. Curve II.—Opalescent Outer Globe.

It will further be noted that there is an abundance of light at all points beneath the lamp, both with shade and with opalescent outer globe.

Figure 19 (see Table 14) shows the results on a lamp fitted with an inner globe having straight side walls. The curve is very strong in the horizontal and falls off at all angles, both above and below.

TABLE 12

LAMP 101

Angle	Test 1	Test 2
55°A		54.2
50		58.6
40	33.5	79.4
30	42.4	122.
20	127.0	128.7
10	154.3	137.4
Hor.	185.0	149.2
10 B	186.2	165.2
20	213.0	175.7
30	239.3	160.0
40	223.1	164.7
50	206.8	152.9
60	200.0	137.6
70	191.0	123.0
80	149.8	82.8

Globes	Op. Inner Clear Outer	Op. Inner Op. Outer
E. M. F.	110 volts	110 volts
Current	6.47 amperes	6.34 amperes
Watts app.	711.7	697.4
Watts	448.	446.
Power factor	.62	.63
Mean hemispherical intensity, H. U.	Upper, 76.7	97.5
	Lower, 205.6	156.
Mean spherical, H. U.	141.1	126.7
Watts per mean spherical, H. U.	3.17	3.52

Whether or not this effect is associated with the shape of this type of globe, I dare not say without further investigation, but the matter can be settled definitely when the tests on inner globes of different shapes are carried out.

Another lamp having a shade is 106. (Table 16, Figure 21.) The shade in this case extends downward

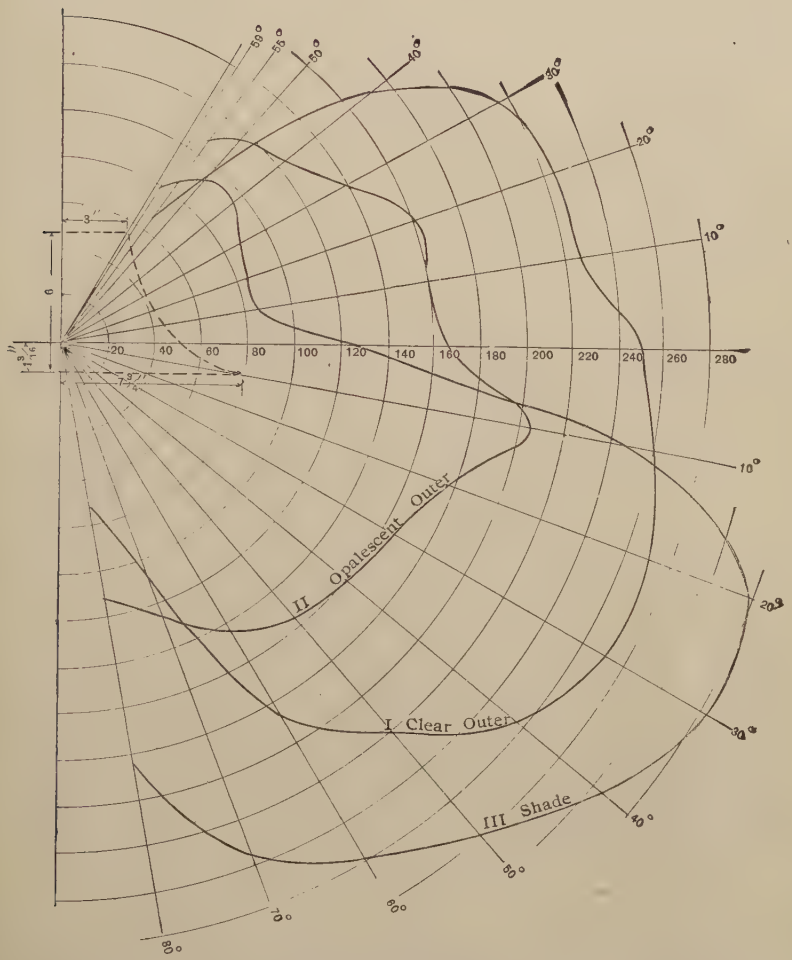

FIG. 18.—LAMP 102.
Curve I.—Clear Outer Globe. Curve II.—Opalescent Outer Globe. Curve III.—Shade.

to a plane about a half-inch above the arc, when the latter is at its highest point. The horizontal intensity with shade is slightly less than with clear outer globe,

showing that the latter strengthens this intensity by diffusion more than it reduces by absorption. The increase in intensity from the horizontal to twenty degrees B is very marked when the shade is employed

TABLE 13

LAMP 102

Angle	Test 1	Test 2	Test 3
59°A			77.6
55	66.1	106.6	
50	96.1	116.7	94.6
40	170.9	123.9	95.0
30	215.7	139.9	86.8
20	223.6	160.7	84.2
10	225.9	159.6	86.1
Hor.	249.8	165.6	124.1
10 B	259.8	204.4	245.3
20	270.4	176.3	317.3
30	270.7	161.1	322.6
40	256.5	161.1	304.6
50	220.8	154.3	280.2
60	184.8	144.8	258.6
70	106.1	125.5	236.6
80	72.6	112.6	186.7

Globes	Op. Inner Clear Outer	Op. Inner Op. Outer	Op. Inner Shade
E. M. F.	110 volts	110 volts	110 volts
Current	6.81 amperes	6.78 amperes	6.77 amperes
App. watts	749.1	745.8	744.7
Watts	459.	483.	457.
Power factor	.61	.64	.61
Mean hemispherical intensity in H. U.	Upper, 169.4	127.2	85.2
	Lower, 236.5	164.8	266.4
Mean spherical in H. U.	202.9	146.	175.8
Watts per mean spherical in H. U.	2.26	3.31	2.60

in the position here indicated, and these are angles of most importance in street lighting, if not in interiors. The mean hemispherical intensity is altered by the substitution of the shade for the clear outer globe in the ratio of 254:169 or fifty per cent as against

thirteen per cent in the case of lamp 102. It is worth noting that the curvature of the two shades is

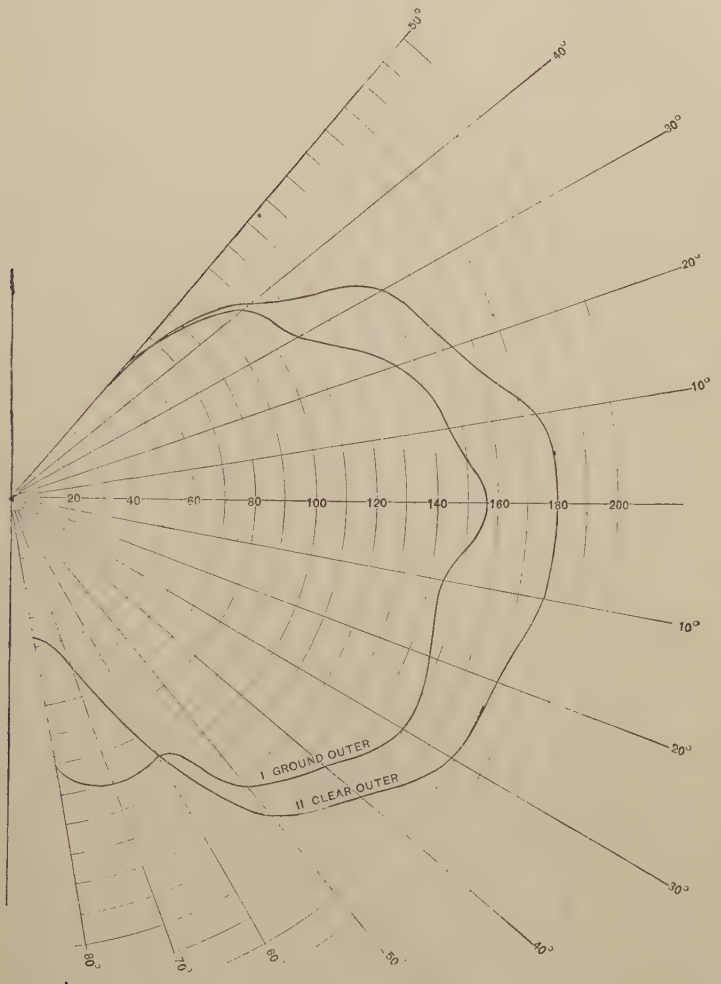

FIG. 19.—LAMP 103.
Curve I.—Ground Outer Globe. Curve II.—Clear Outer Globe.

opposite—that of 106 being such as to reflect light incident at high angles, so as to make it useful, while

that of 102 throws light incident at angles higher than about twenty-five degrees A upwards, where it is, in a large measure, dissipated by multiple reflection and absorption. This fact accounts, I think, for the

TABLE 14

LAMP 103

Angle	Test 1	Test 2
50°A	59.8	50 7
40	98.0	101.6
30	108.0	140.3
20	133.6	153.9
10	145.8	174.7
Hor.	156.9	180.2
10 B	145.1	179.2
20	147.4	172.2
30	150.3	169.1
40	136.5	152.3
50	123.6	136 5
60	99.4	96.0
70	101.0	59.8
80	89.9	47.3

Globes	Op. Inner Ground Outer	Op. Inner Clear Outer
E. M. F.	110 volts	110 volts
Current	5.91 amperes	5.87 amperes
App. watts	650.1	645 7
Watts	424.	410.
Power factor	.65	.63
Mean hemispherical intensity in H U	Upper, 98.2 Lower, 133.2	113. 146 8
Mean spherical in H. U.	115.7	129.9
Watts per mean spherical, H. U.	3.66	3.15

great difference in these two examples of the employment of a shade. The low, flat shade, concave inwards, is certainly superior optically, if not artistically.

As to the efficiency of this type of lamp, we have in Table 19 a recapitulation of the power measurements in the alternating-current lamps. The mean

power consumption of seven lamps is 417 watts. The average value of the mean spherical intensity is:

With clear outer globe, 159 H. U.
" opalescent outer globe, 130 H. U.

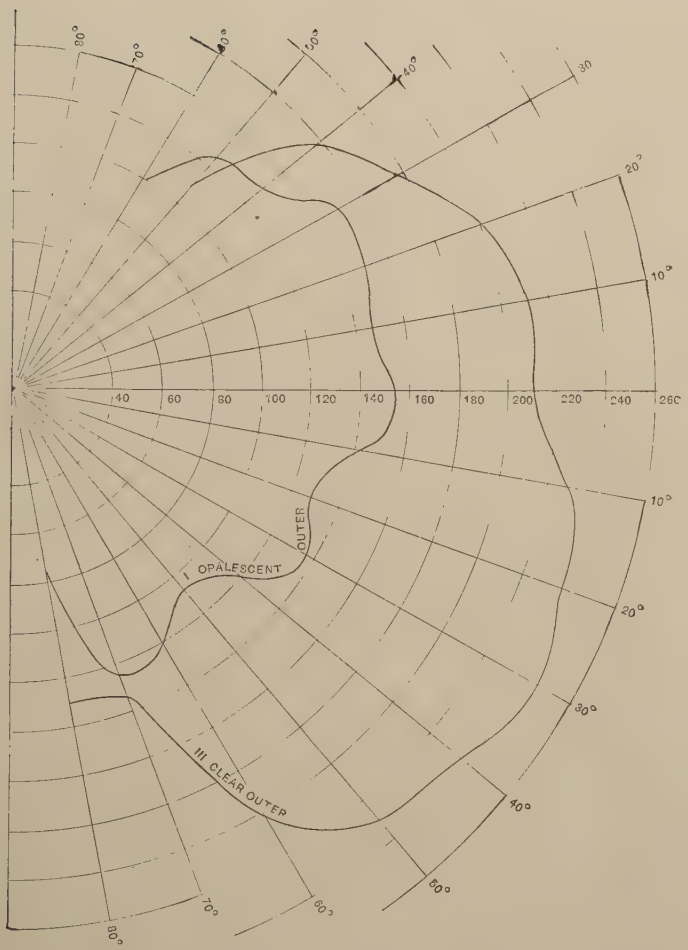

FIG. 20.—LAMP 105.
Curve I.—Opalescent Outer Globe. Curve III.—Clear Outer Globe.

Therefore, as light producers, the average efficiency is:

With clear outer globe, 2.62
" opalescent outer globe, 3.21

in watts per mean spherical Hefner unit. The mean power in the arc is 342 watts, and in the mechanism 74 watts.

TABLE 15

LAMP 105

Angle	Test 1	Test 3
59°A	99.9	
55		
50	124.0	109.3
40	129.0	157.8
30	149.1	177.1
20	150.4	205.7
10	146.3	211.2
Hor.	153.4	211.2
10 B	142.2	228.3
20	128.1	236.6
30	137.6	244.6
40	121.0	236.1
50	107.0	231.1
60	120.6	202.9
70	125.1	134.9
80	77.0	131.1

Globes	Op. Inner Op. Outer	Op. Inner Clear Outer
E. M. F.	110 volts	110 volts
Current	6.21 amperes	6.19 amperes
App. watts	683.1	680.9
Watts	414.	410.
Power factor	.60	.60
Mean hemispherical intensity in H. U.	Upper, 128.4 Lower, 127.3	154.8 218.8
Mean spherical in H. U.	127.8	186.8
Watts per mean spherical in H. U.	3.24	2.20

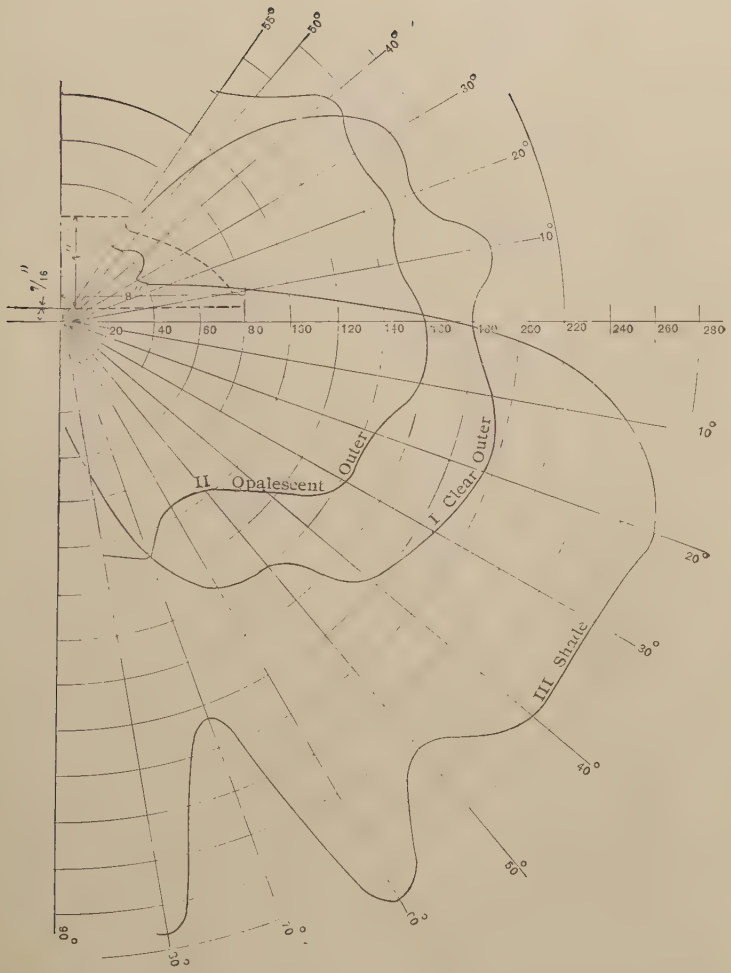

FIG. 21.—LAMP 106.

Curve I.—Clear Outer Globe. Curve II.—Opalescent Outer Globe. Curve III.—Shade.

TABLE 16

LAMP 106

Angle	Test 1	Test 2	Test 3
55°A	59.9	39.5	122.9
50	90.8	40.1	129.2
40	139.1	44.0	152.4
30	164.9	36.8	147.3
20	163.7	46.7	152.6
10	189.7	79.0	149.4
Hor.	179.9	174.9	159.0
10 B	191.9	251.9	158.4
20	196.4	276.2	145.7
30	188.0	268.4	143.3
40	177.7	269.1	117 2
50	140.7	244.8	98.2
60	136.5	293.6	95.2
70	108.1	186.6	109.9
80	63.4	272.5	103.8

Globes	Op. Inner Clear Outer	Op. Inner Shade	Op. Inner Op. Outer
E. M. F.	110 volts	110 volts	110 volts
Current	6.1 amperes	6.1 amperes	6.17 amperes
App. watts	671.	671.	678.7
Watts	392.	378.	371.
Power Factor	.58	.56	.54
Mean hemispherical intensity in H. U.	Upper, 136.8	49.6	132.8
	Lower, 169.5	254.4	130.4
Mean spherical in H. U.	153.1	152.	131.6
Watts per mean spherical in H. U.	2.56	2.49	2.82

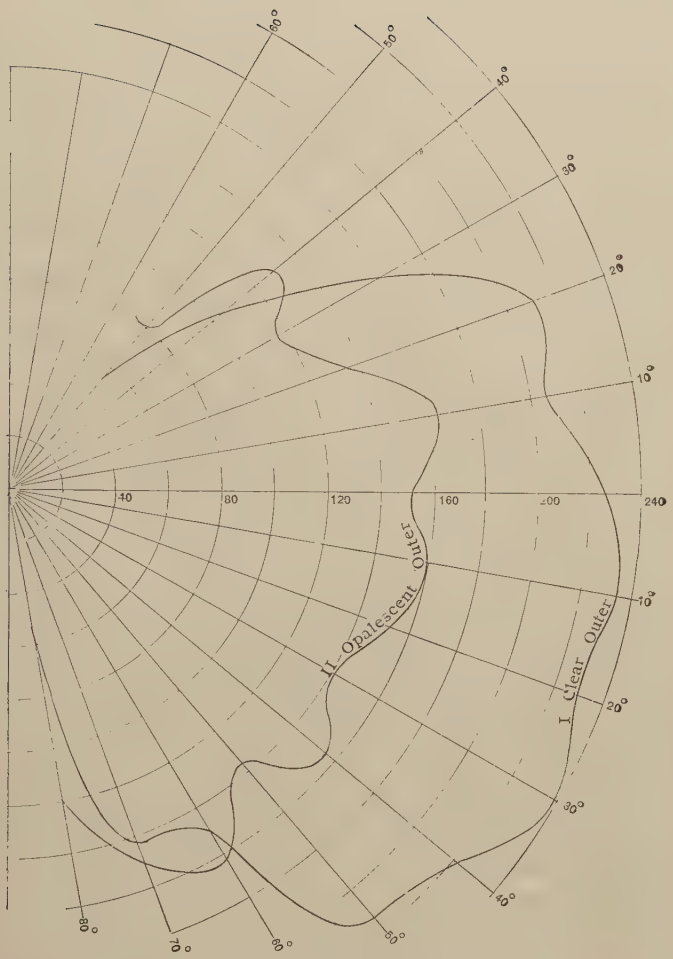

FIG. 22.—LAMP 108.

Curve I.—Clear Outer Globe. Curve II.—Opalescent Outer Globe.

TABLE 17

LAMP 108

Angle	Test 1	Test 2	Test 3
55°A		82.9	52.2
50	55.8	80.9	111.2
40	105.1	130.7	186.6
30	159.0	116.5	216.1
20	210.7	134.5	220.5
10	206.0	163.3	217.9
Hor.	225.1	151.9	183.2
10 B	234.4	160.5	219.0
20	229.4	153.3	249.2
30	239.1	142.9	279.1
40	222.6	156.7	279.3
50	215.8	137.7	224.4
60	150.2	162.9	204.7
70	143.0	150.9	231.7
80	52.6	121.1	151.2

Globes	Op. Inner Clear Outer	Op. Inner Op. Outer	Op. Inner Coated. Clear Outer
E. M. F.	110 volts	110 volts	110 volts
Current	6.56 amperes	6.47 amperes	6.41 amperes
App. watts	721 6	711.7	705.1
Watts	457.5	440.	462.
Power factor	.63	.61	.65
Mean hemispherical intensity in H. U. Upper	139.9	115.9	167.5
Mean hemispherical intensity in H. U. Lower	211.2	150.4	233.7
Mean spherical, H. U.	175.5	133.1	200.6
Watts per mean spherical, H. U.	2.61	3.30	2.30

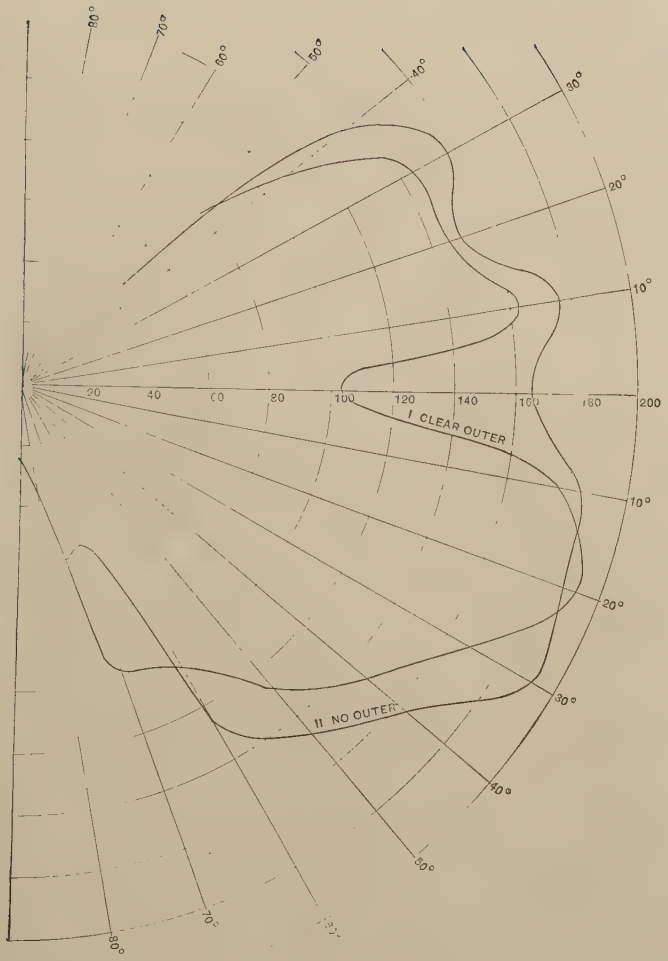

FIG. 23.—LAMP 110.

Curve I.—Clear Outer Globe. Curve II.—No Outer Globe.

TABLE 18

LAMP 110

Angle	Test 1	Test 2
45° A	80.4	66.4
40	106.6	132.9
30	144.2	157 2
20	146.2	149.4
10	162.6	176.4
Hor.	103.3	165.2
10 B	176.2	184.7
20	192.8	187.6
30	168.7	192.0
40	147.2	164.7
50	128.7	148.4
60	105.5	126.3
70	98.6	55 3
80	36.5	70.4
Globes	Op. Inner Clear Outer	Op. Inner No Outer
E. M. F.	110 volts	110 volts
Current	6.07 amperes	6.3 amperes
App. watts	667.7	693.
Watts	339.	338.
Power factor	.50	.48
Mean hemispherical intensity in H. U.	Upper, 109.6	118.4
	Lower, 143.2	161.6
Mean spherical in H. U	126.4	140.
Watts per mean spherical in H. U.	2.68	2.41

TABLE 19

POWER MEASUREMENTS

	Total	In Arc	Mechanism
Lamp No. 101	448	340	108
" " 102	459	375	84
" " 103	424	344	80
" " 105	414	382	32
" " 106	378	298	80
" " 108	457	383	74
" " 110	339	276	63

THIRD—A REPORT ON THE RELATIVE VALUE OF DIRECT AND ALTERNATING-CURRENT LAMPS.

The lamps used in the two foregoing investigations, considered as types, are unfortunately not of the same power consumption, but regarding them merely as light producers, the average direct-current lamp yields, with opalescent inner and a clear outer globe, 207 h. u., whereas the average alternating-current lamp for circuits of the same pressure yields 159 h. u., which gives the former lamp an advantage as a light source, irrespective of efficiency, in the ratio of 48:159 or thirty per cent. It is pretty well demonstrated that the alternating arc is *per se* less efficient than the direct-current arc. Just what the proper ratio may be is a matter for physical research, and varies with several factors, such as current density, wave form, character of the circuit, etc. We have no data in these investigations to furnish reliable information on this point, as there are too many variable conditions met in the lamps as found in their commercial form.

Comparing the average performance of the lamps in the first series of tests with the average performance of the lamps in the second series of tests, one finds very nearly the same power consumption per light unit, namely:

	D. C.	A. C.
Clear outer	2.60	2.62
Opalescent outer	3.04	3.21

This result differs from one that I have formerly published, which shows the direct-current lamp, as a result of a *single* comparison as superior in economy to the other type. I consider the combined result of

these tests as of far greater value than the result of the single comparison. Moreover, a considerable improvement in the alternating-current lamp has doubtless taken place in the last two years, whereby its economy, as well as its operation, are found to be bettered.

Question of design, steadiness of operation, carbon consumption, etc., are purposely left out of this comparison until such time as more data shall be available.

To compare the direct-current lamp with the alternating-current lamp on the basis of mean spherical intensity is not always fair. When a diffusing outer globe is used, this basis of comparison is correct enough, for the reason that the distribution of intensity is fairly constant in all directions, both for the direct and alternating-current types.

For outdoor use, however, lamps will be provided with inner globes only, or clear outer globes, or shades, as the case may be. In any event, the upward luminous flux which passes the globes or shades is practically of no utility. Hence for outdoor use the mean hemispherical intensity below a plane passing through the arc is a better basis for comparison.

Now, the average direct-current lamp in this series of tests yields a mean hemispherical intensity of 273 h. u. with clear outer globe. The average alternating-current lamp yields but 190 h. u. This gives the former an advantage as a useful light source represented by the ratio of 83:190, or 43.7 per cent. Moreover, the power required per unit intensity is in the two cases 1.97 watts and 2.19 watts per mean hemispherical h. u., so that not only does the direct-current lamp with clear outer globe give a stronger mean intensity below the arc, but it does so at a higher efficiency. But it is wasteful to use an alter-

nating-current lamp for street lighting without a shade or reflector. The tests on lamps 102 and 106 enable one to draw certain interesting comparisons. They give mean hemispherical intensities respectively of 266 and 254 h. u., or very nearly the same as the average direct-current lamp with clear outer. This yield is obtained at a power consumption of only 418 watts, which is 1.61 watts per h. u. This emphasizes the great importance of a shade on the alternating-current lamp. Finally, we may compare this last result with the performance of direct-current lamp 1, *with no outer globe* and no shade. Here the mean hemispherical intensity is 362 h. u., the power consumption 558 watts and the power per h. u. 1.54 watts. The conclusion, based on this single comparison, is that for street lighting the 550-watt (nominal rating) direct-current lamp without shade gives 39 per cent more useful light than the 450-watt (nominal rating) alternating-current lamp with shade and at slightly greater economy.

But the fact must not be lost sight of that this last comparison is between constant potential inclosed arcs as found on the market. The question of the light output and efficiency of the series alternating inclosed arc of the same power as the direct-current lamp will be taken up later.

Table 20 gives a summary of the results in the two foregoing investigations. I have also plotted (Figure 24) what may be termed a *composite* curve for each type. These curves are nothing more than means of the foregoing individual curves for a clear outer globe. The irregularities due to differences in globes, reflecting surfaces, and other causes are found to largely neutralize each other with the result of the smooth loci here shown. These two curves will be

TABLE 20.

D. C. Lamp.	Current.	Watts Consumed.			Mean Intensity in H. U.			Mean Watts.		
					Spherical.		Lower Hemispherical.	Spherical H. U.		Lower Hemispherical.
		In Lamp.	In Arc.	Mechanism.	Op. Outer	Clear Outer	Clear Outer	Op. Outer	Clear Outer	Clear Outer
1	5.01	551	401	150	172	235 256*	332 362*	3.10	2.37 2.18*	1.66 1.52*
3	5.08	559	406	152	195	216	282	2.85	2.60	1.99
4	4.76	524	381	143	127	139	208	4.12	3.76	2.52
5	4.16†	458	333	125	154	174	221	2.96	2.63	2.07
7	4.76	524	381	143	203	333	317	2.63	2.20	1.65
9	4.84	532	387	145	182	226	281	2.83	2.38	1.89
10	4.99	549	399	150	202	242	309	2.74	2.24	1.77
12	4.87	536	390	146	178	195	230	3.05	2.66	2.33
Mean	4.9	529	384	144	176	207	272	3.03	2.60	1.98
A. C. Lamp.			Power Factor Lamp.		Power Factor Arc.					
101	6.40	448	.63	340	.82	108	127	141	206	352	317	2.17
102	6.79	459	.61	375	.73	84	146	203 176†	236 266†	3.31	226 260†	1.94 1.72†
103	5.89	424	.65	344	.75	80	116	130	147	3.66	3.15	2.88
105	6.20	414	.61	382	.80	32	128	187	219	3.24	2.20	1.89
106	6.12	378	.56	298	.70	80	132	153 152†	169 254†	2.82	2.56 2.49†	2.23 1.48†
108	6.48	457	.64	383	.80	74.5	133	175	211	3.30	2.61	2.16
110	6.18	339	.49	276	.72	63	140*	126	143	2.41*	2.68	2.37
Mean	6.29	417	.60	342	.76	74.5	130	159	190	3.31	2.66	2.23

* Condition of no outer globe. † Condition with shade on Lamp.
NOTE—All marked values not included in the mean.

found valuable for the plotting of curves of illumination.

Absorption of Globes:

The results of the first and second investigations enable one to obtain some interesting figures on the absorption of the outer globes. It is evident that if we take the mean spherical intensity of any lamp with a clear outer globe, and divide it by the intensity

obtained with no outer globe, we get a ratio that show the transmission of the clear globe. I am able to get this ratio in three cases. The values are 91.7,

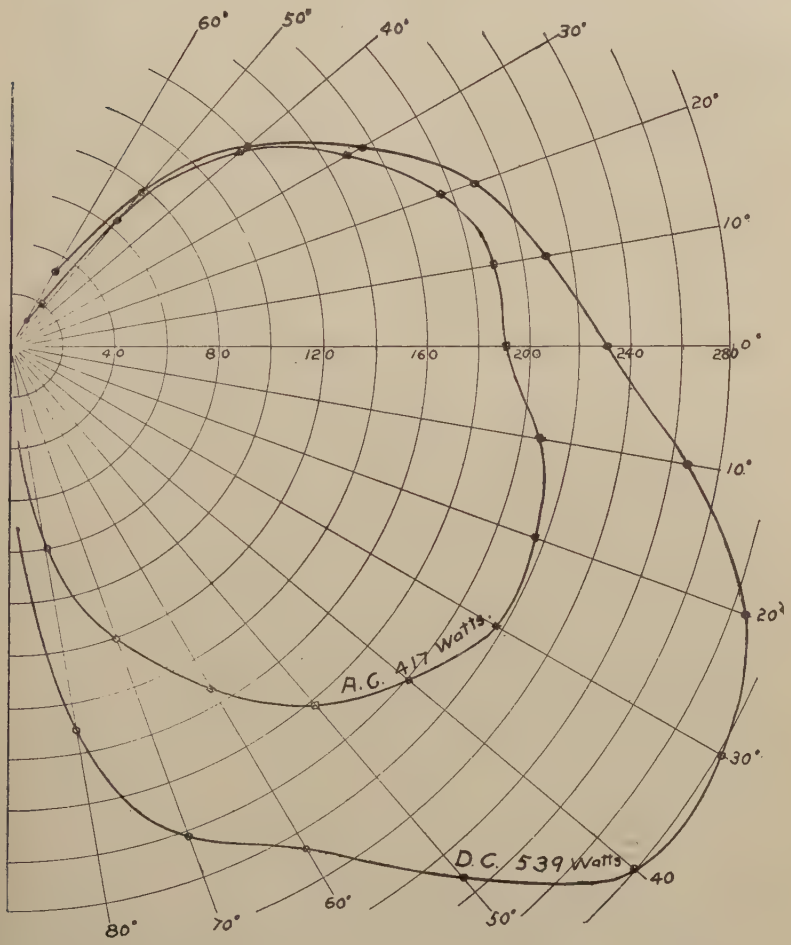

Fig. 24.

90.3 and 88.8. The mean of these is 90.2. In other words, a clear globe cuts down the luminous flux from the inner globe by about ten per cent. In a

similar way two opalescent globes were found to produce an absorption of 21.8 and 32.4 per cent, or a mean of 27.1 per cent. These figures give what may be termed the absolute absorption of the clear and opalescent globes. We may also find the relative transmission (understanding the term transmission in a very general sense, that is to say, having in mind both diffusion and absorption) of the opalescent and clear outer globes by taking the ratio of the corresponding mean spherical intensities. Following are the values: 73.6, 90.3, 91.3, 88.9, 87.2, 80.7, 83.9, 91., 89.8, 72., 89.1, 69.4, 86., 75.8. The mean of the values is 83.5. It will be noted that there is a wide variation in these figures, the lowest being 69.4 and the highest 91.3. To look at the matter in another way, if we substract each one of these values from 100, we have a series of numbers that represent the diminution in mean spherical intensity resulting from the substitution of an opalescent globe for a clear globe in each case. The wide variations might have been predicted from a casual examination of the globes as sent by the manufacturers. Herein lies one large factor of uncertainty in determining the relative lighting value of different makes of inclosed arc lamps.

FOUR AND FIVE—INVESTIGATIONS ON THE COATING OF THE INNER GLOBE.

As regards the work called for under these headings, I am unable to do more at this date than to give the results of certain tests and experiments undertaken tentatively with a view of getting at the best method of procedure. Attention has already been called to the fact that the change in the intensity of an arc-lamp with the burning away of the

carbons is due principally, if not entirely, to two factors, one of which is the coating formed on the inner globe. It becomes important to know the time-law of formation of this coating. To this end, several lamps, of both the direct and alternating-current types, were fitted with carbons and started on a time run. At intervals, the inner globes were removed and tested photometrically for absorption by placing inside of them a slender incandescent lamp maintained at constant intensity. It is not to be expected that the total absorption of such globes can be independent of the distribution of luminous intensity about the source within the globe. That is, the actual absorption with the glow lamp is likely to be different from that with the arc, yet the change in the absorption as the coating forms could not, it was thought, differ to any marked extent with the nature of the source. The results of these tests have not, as a rule, been very satisfactory, owing to a variety of complications which I need not here discuss. However, certain interesting points are made manifest from a consideration of the most uniform of these results. If we reduce the various intensities from the glow lamp at different angles to unity by dividing intensities in any given direction by the initial intensity in that direction, we have the effect of a source giving a uniform light in all directions. The falling of the intensities at different angles with time in the case of a direct-current lamp is shown in Figure 25, wherein the dotted lines represent the change in intensity at different angles, and the full curve the change in mean spherical intensity. The upper set of curves is for the angles above the horizontal; the lower set for the angles below the horizontal. The curves show clearly that the coating forms most heavily on the

upper part of the globe, a fact which is apparent from the appearance of the globe. A fact which is not so apparent, but one which the curves bring out

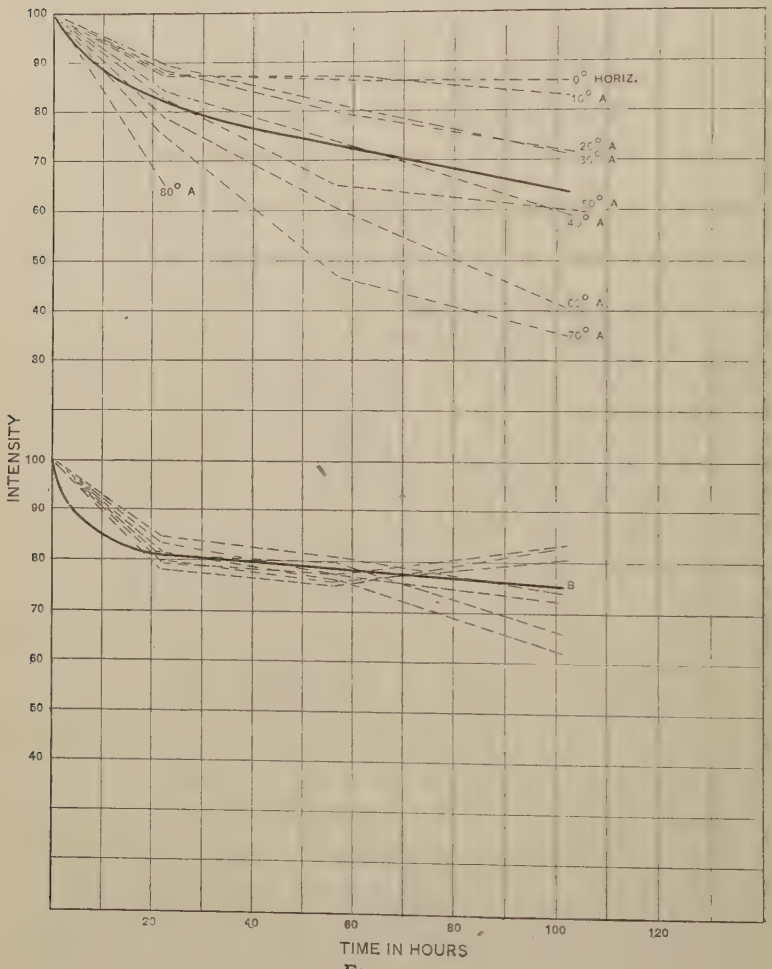

FIG. 25.

clearly, is that the coating forms very rapidly at first and then gradually decreases in rate of formation, or, to be more accurate, the absorption of light changes

in this way. It will be noted that the mean hemispherical intensity falls from 100 to 64 in 100 hours.

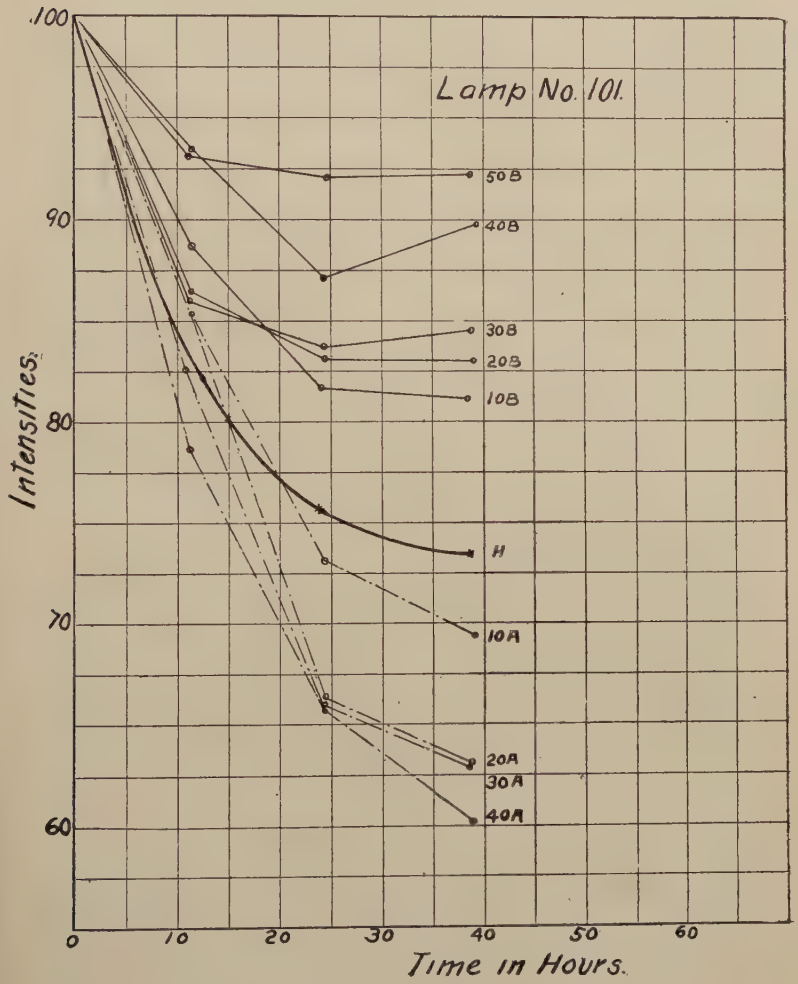

Fig. 26.

Below the horizontal, the falling off in the same time is from 100 to 76.

Figure 26 shows the formation of the coating in

the case of an alternating lamp during a period of forty hours. Here again the coating forms most rapidly above the horizontal.

In the case of four alternating lamps the inner globes were weighed at intervals. When these weights are plotted against time we have the set of curves in Figure 27, extending from the origin upwards. Unlike

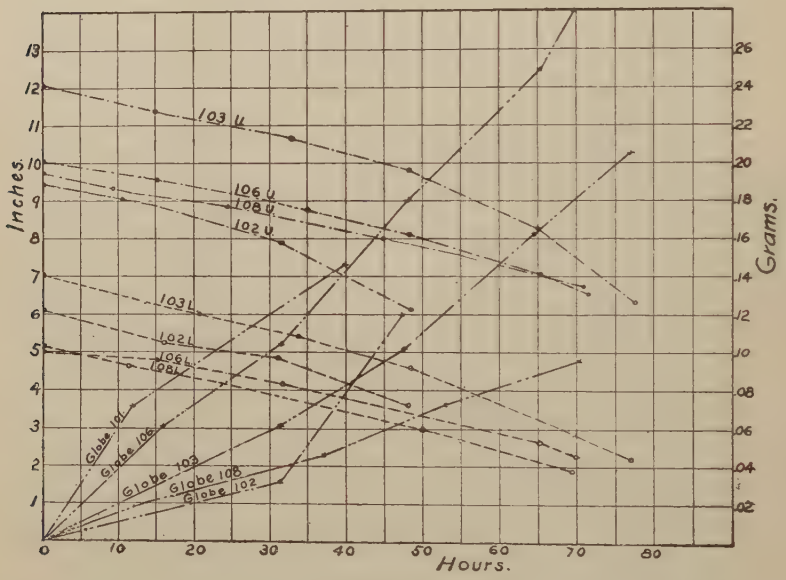

FIG. 27.

the absorption curves, these loci show an increasing rate of deposit with the life of the lamp. It is not to be expected that the increase in the mass of the deposit and in the amount of light cut off by the deposit should follow the same law. It seems reasonable that successive equal increments of coating might cut off diminishing increments of light, and the trend of the curves seems to indicate this clearly.

It was not intended to take up the matter of carbon life until a thorough study of the matter could be made apart from other things. However, as the

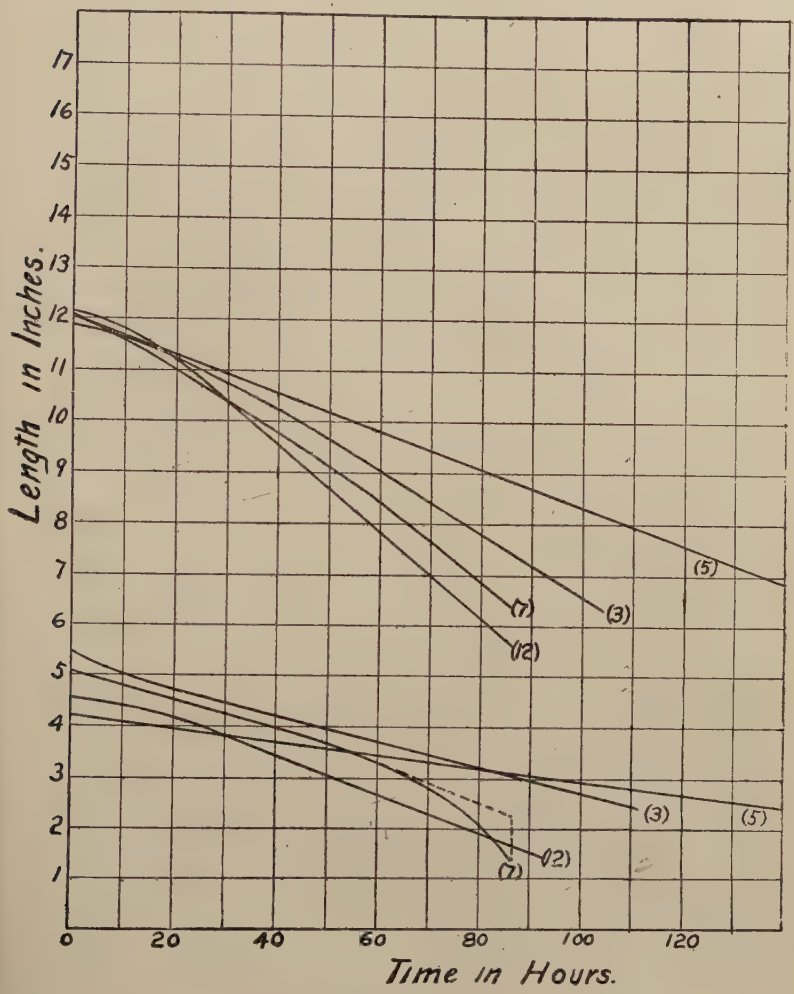

FIG. 28.

weights of the carbons were taken at intervals during the runs made for the sake of the coating, I am able to plot certain curves of carbon consumption which

may be indicative of what may be found under a more extended investigation. The upper and lower carbon life curves of four alternating-current lamps

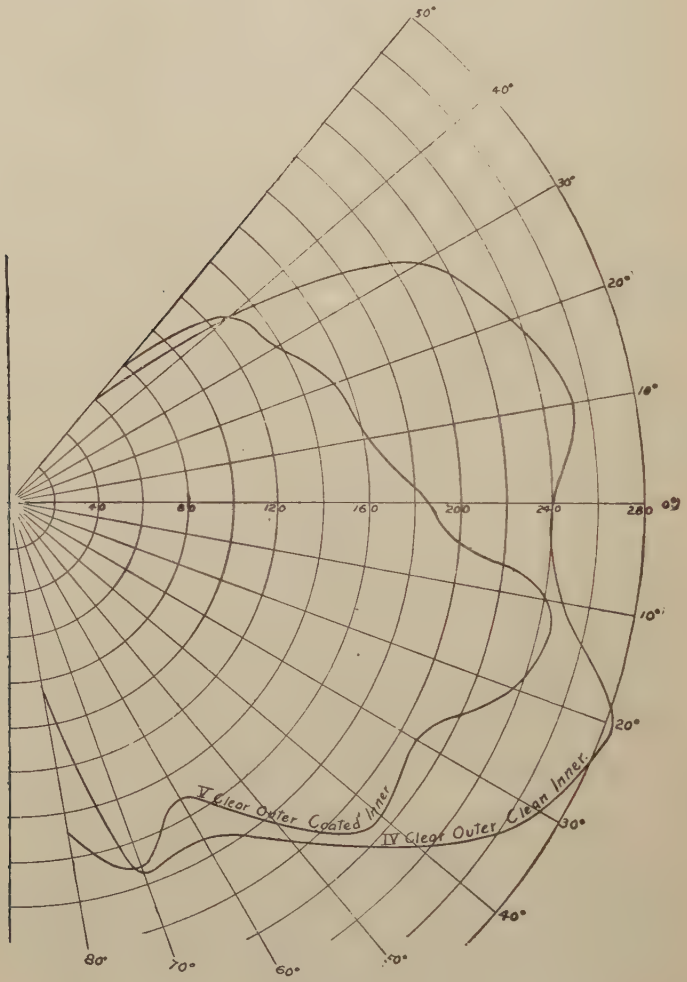

FIG. 29.

appear in Figure 27. There seems to be a tendency for the carbons to burn more rapidly towards the end of the life. This corresponds to the upward tendency

to be noticed in all the weights of coating, except one. The life of the lamps, on one trimming, is in the vicinity of seventy hours. Lamp 102 cut out in 47.5 hours because of the rapid combustion of the upper carbon—the lower carbon being still quite long. There may have been some abnormal conditions in this case unknown to the observers.

Figure 28 shows a similar set of curves for four direct-current lamps. Lamp 7 failed to cut itself out and the bottom of the globe was fused. This accounts for the sudden drop in the curve of the lower carbon. Of these lamps, number 5 shows the longest life, the run not having terminated when the last measurement was made. Here, again, we note the accelerated combustion toward the end.

I am able, at this time, to give the results of some initial and final tests which bring out the joint effect of the coating and the descending arc. Thus Figure 29 shows an initial and final test on lamp 12 (see table 9, tests 4 and 5). The absorption in this case is 16.4 per cent, after 106 hours. Another brand of carbons in this lamp gives the results found in table 10. One notes here a considerably higher initial intensity, but, on the other hand, a much heavier coating, the final absorption after 105 hours being 35.2 per cent. This lamp was fitted with an inner globe of the closed bottom type. The other type of inner globe presents less surface for the reception of the ash, and one would look for a larger light absorption at the end of the carbon life. A preliminary test on lamp 7 (see table 6) shows that the loss in intensity at the end of the life was 36.5 per cent.

In Figure 30, which represents the result of a coating test on an alternating-current lamp, one finds the striking result of *more light with coating than*

without. (See table 17.) The absorption is 14.3 per cent. It is important here to remember that, with the

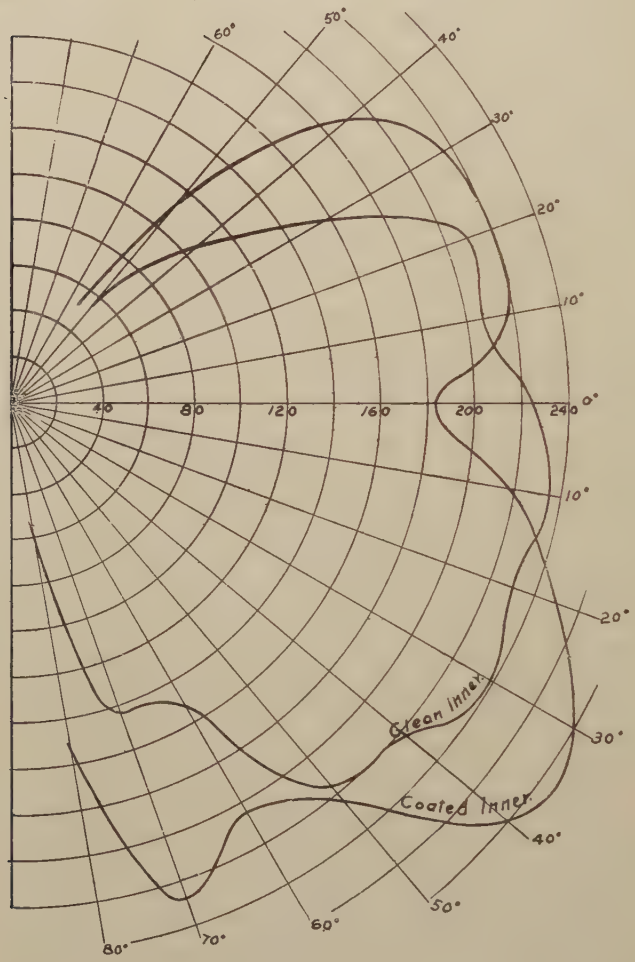

FIG. 30.

arc at the top, the strong upper lobe of the distribution curve of the alternating arc is very much curtailed. Now, as the arc lowers, this lobe unfolds, as

it were. In seventy hours' time the coating has not formed with sufficient rapidity to offset this increase in luminous flux. Hence the result shown.

PART III.

AN IMPROVED APPARATUS FOR ARC-LIGHT PHOTOMETRY.

A paper presented at the 156th Meeting of the American Institute of Electrical Engineers, New York, September 27th, 1901.

[ADVANCE COPY SUBJECT TO REVISION.]

AN IMPROVED APPARATUS FOR ARC-LIGHT PHOTOMETRY.

BY CHARLES P. MATTHEWS.

The usual process in arc-light photometry involves the determination of the distribution curve of luminous intensity in a vertical plane through the axis of the carbons, and the subsequent integration of a derived curve in rectangular co-ordinates (the Rousseau diagram).[1] The ordinate of this latter curve is the measured intensity, and the increment of the abscissa is proportional to the area of the elementary zone which such intensity illuminates of an imaginary sphere about the source. The mean ordinate of this derived curve is the value sought. Under the most favorable conditions this task is a tedious one, several hours being usually required for its completion.

Methods designed to shorten this process, through the production upon the photometer screen of an illumination proportional to either the mean spherical or mean hemispherical intensity of the source are not new. Of these integrating methods, the writer is aware of two due to Blondel,[2] and one due to Houston and Kennelly.[3]

Unfortunately, two of these methods are adapted only to the photometry of the open arc, while the third, although worked

1. See Appendix.

2. The Lumenmètre. *L'Éclairage Électrique*, March, April, May, 1895. The Photomesomètre. *L' Éclairage Électrique.*

3. *Electrical World*, xxvii: 509. 1896.

out in a masterly manner by Blondel, requires a somewhat elaborate preliminary calibration. It is the writer's purpose to describe here an equipment which he has designed for the Photometric Laboratory of Purdue University, where it is now in satisfactory operation. This piece of apparatus, while embodying certain features of Blondel's apparatus, combines simplicity of operation with adaptability to either the open or enclosed arcs.

Theory of the Method.

The mean spherical intensity and the mean hemispherical intensity of a source whose photometric surface is one of a revolution are given by the expressions:

$$I_{ms} = \frac{1}{2} \int_0^{\pi} I_\theta \sin \theta \, d\theta^*$$

$$I_{mhs} = \int_0^{\pi/2} I_\theta \sin \theta \, d\theta.$$

Where I_θ is the intensity at an inclination of θ to the vertical. If the intensity I_θ be taken at n equal intervals through 180°, or n' equal intervals through 90° in a vertical plane, we may write

$$I_{ms} = \frac{\pi}{2n} \sum_0^{\pi} I_\theta \sin \theta$$

as the mean spherical intensity and

$$I_{mhs} = \frac{\pi}{2n'} \sum_0^{\pi/2} I_\theta \sin \theta$$

as the mean hemispherical intensity—expressions which are quite correct if n and n' be sufficiently large.

For example, let us consider the hypothetical distribution of intensity shown in Fig. 1, namely, a circle tangent to a vertica line. Here I is a known function of θ and we have

$$I_{ms} = \tfrac{1}{2} \int_0^{\pi} I_0 \sin^2 \theta \, d\theta$$

$$= 78.5$$

if I_0 be taken as 100.

*See Appendix.

Taking now $\triangle \theta = 15^\circ$ or $n = 12$, we have

TABLE I.

θ	$100 \sin^2 \theta$
0	0.
15	6.7
30	25.
45	50.
60	75.
75	93.3
90	100.
105	93.3
120	75.
135	50.
160	25.
175	6.7
	600.

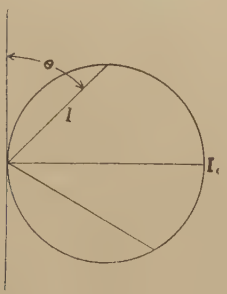

FIG. 1.

Whence

$$\sum_0^\pi 100 \sin^2 \theta = 600 \text{ and } I_{ms} = \frac{\pi}{2 \times 12} \times 600 = 78.5$$

It thus appears that with $n = 12$, the approximate formula yields a result amply correct.

To produce on the photometer screen an illumination proportional to the mean spherical intensity of the source, it is necessary, as the formula shows, (1) to direct towards the photometer the beams of light which the eye of an observer would receive if he were to view the source at angular intervals of 15 degrees in a vertical plane, and (2) to reduce the intensity of the light in these directions in the ratio of the sine of the angle between the direction of view and the vertical. The method of accomplishing this is described below.

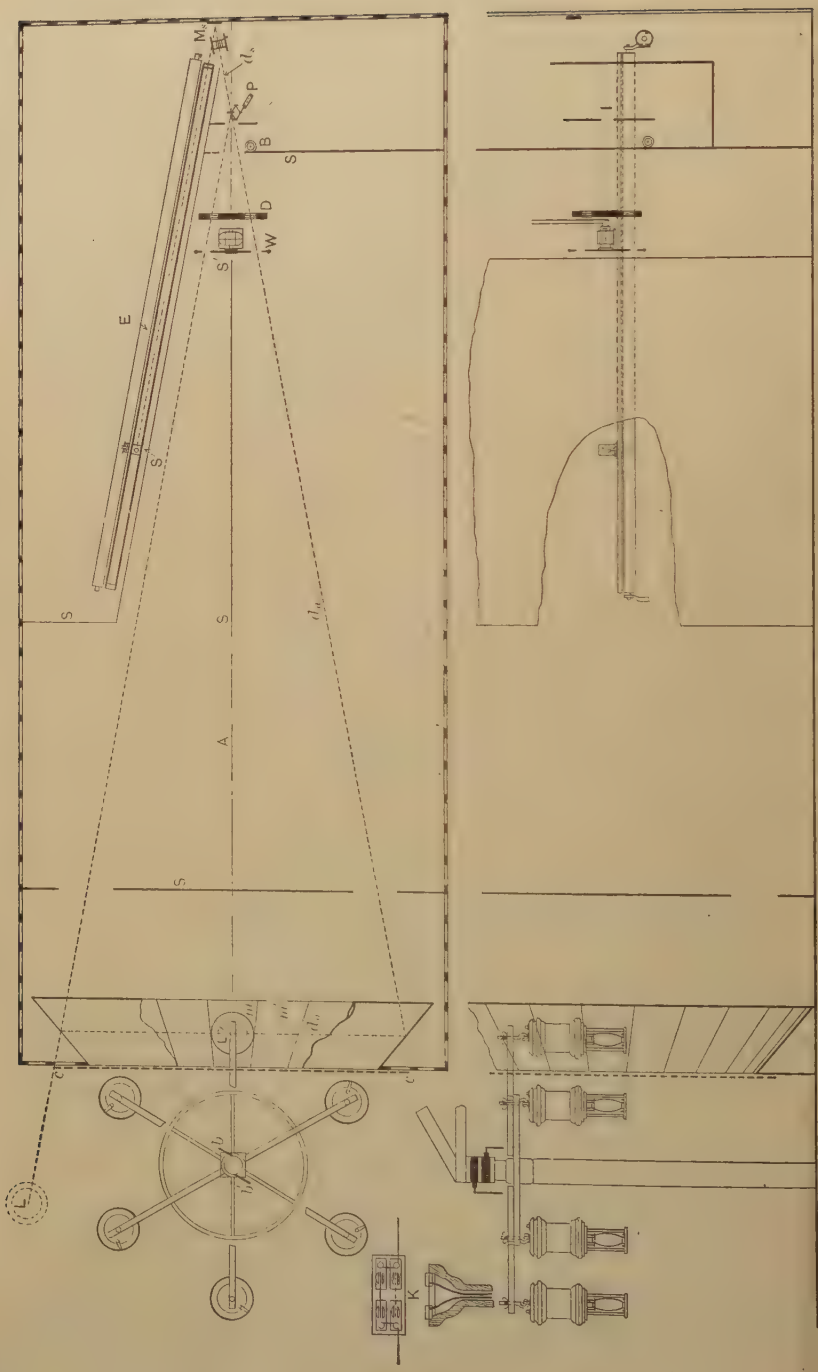

FIG. 2.—Plan and Elevation of Photometer Room.

Description of Method.

A ring of 24 large trapezoidal mirrors, M, M, surrounds the arc. This system of mirrors constitutes a truncated, 24-sided pyramid. The inclination of the mirrors to the axis A of the system is such that the eye, placed at the photometer P, sees 24 images of the lamp L, of which L′ is the horizontal one, precisely as if the mirrors being absent, one were to travel in a circle about the arc in the plane 00′ stopping at 15° intervals. Figs. 3 and 4 show the aspect of this series of images from a point

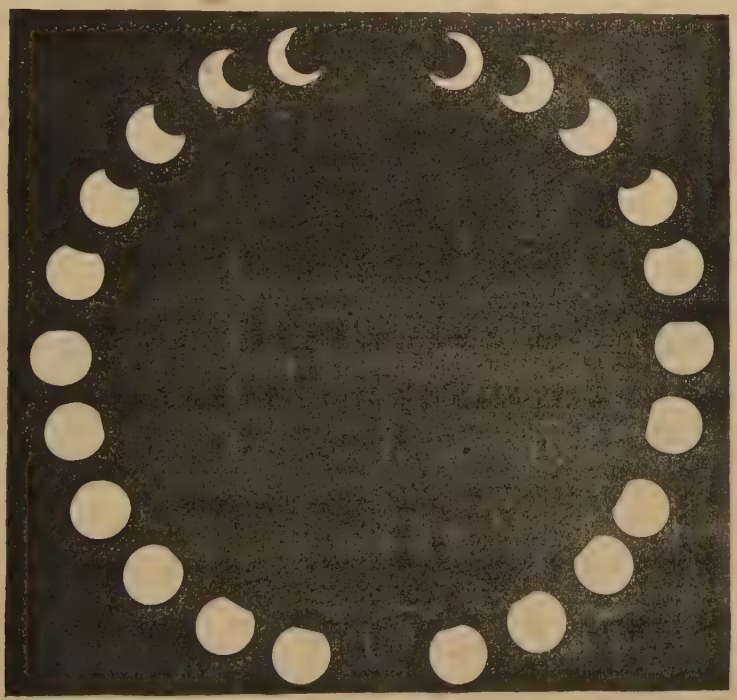

Fig. 3.—Arrangement for the Determination of the Mean Spherical Intensity. [The slight amount of dispiacement in Figs. 3 and 4 is due to the fact that the camera could not be placed in the optical center of the system.]

near the photometer. The first figure shows the entire set of images as used in the determination of the mean spherical intensity, and the second figure the lower images only for the determination of the mean hemispherical intensity, as in the case of lamps with shades. As actually used, the top and bottom mirrors were left out, not because there may not be light in these

directions, but because these intensities, when multiplied by sine 0°, do not contribute to the mean spherical intensity. Direct light from the arc is intercepted by a black screen s.

This system of mirrors serves then to direct the light to the photometer screen in the chosen directions. The second condition is that the intensity of each beam of light shall be reduced in the ratio of the sine of the vertical angle. I have done this by a polygonal glass disk D, composed of as many sectors as there are mirrors. These sectors are smoked until they give the desired absorption. In order that the film of smoke may be permanent, the ring of smoked sectors is covered by two plates

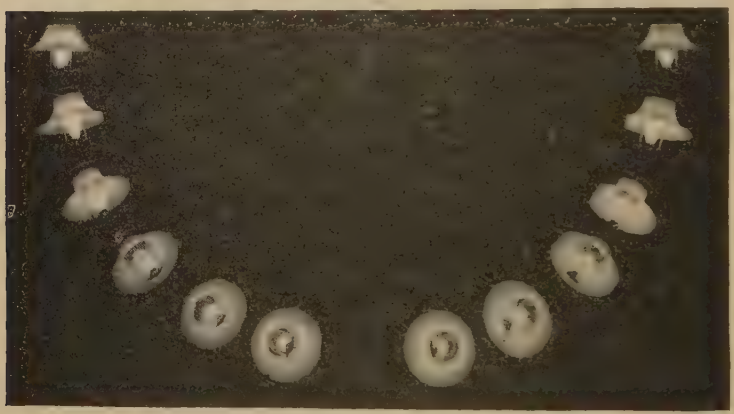

FIG. 4.—Arrangement for the Determination of the Mean Hemispherical Intensity.

of plane glass. These plates cover but do not touch the smoked surfaces. The three thicknesses of glass are firmly bound together, and the screen as a whole may be handled without fear of changing its absorption. The precaution must be taken to thoroughly clean its external surfaces before making measurements. An essential condition to the success of this method is that the photometer screen should receive light through any given sector from the image in the corresponding mirror and from no other. That this condition is fulfilled, can easily be determined. Thus, if all the mirrors be covered except the horizontal one, and all the sectors be covered except the sector just above the horizontal, that is, at 15° A, then if the patch of light produced by this arrangement of the apparatus falls not

upon the photometer screen, but upon the black surface in the vicinity of the photometer, the required condition is met. The sectored disk is best put in place by replacing the photometer screen by a cardboard pierced by a small opening. The observer can then sight through this hole, and ascertain the adjustment of the disk with reference to the system of mirrors.

Constants of Mirrors and Glass.

The mirrors are of good quality, French plate glass. Their reflection coefficients were carefully determined for the incidence at which they are used. Some inequalities were found, as would be expected, although the maximum difference from the mean value of .815 is only $\pm$ 2.9 per cent. The following table gives the coefficients of the 24 mirrors.

TABLE II.

Value of Mirror Coefficients K_θ.

Mirror Number.	K_θ	Mirror Number.	K_θ
1	.796	13	.820
2	.830	14	.832
3	.803	15	.798
4	.814	16	.818
5	.791	17	.818
6	.812	18	.809
7	.812	19	.798
8	.803	20	.812
9	.832	21	.812
10	.809	22	.812
11	.839	23	.830
12	.834	24	.812

It will be seen that these coefficients occur in pairs. This would lead one to believe that two mirrors were cut from one piece of glass. An inspection of the edges of the mirrors showed that this was very probably the case. The values are so nearly equal that for purposes of arc-light photometry sufficient accuracy would be obtained by using the mean value of .815. However, in order that the apparatus might be used for the measurement of steady sources, I have made up for variations in K_θ in the smoking of the corresponding glass sectors. That is to say, if the coefficient of a particular mirror were high, the corresponding glass sector was smoked a little heavier than would otherwise be done. In all cases the formula

$$(K_g\ K_s)\ K_\theta = (K_0\ K_g) \sin\theta$$ was satisfied.

Where K_g = transmission coefficient of glass

K_s = transmission coefficient of layer of smoke corresponding to angle θ.

K_θ = reflection coefficient of mirror at angle θ

K_0 = reflection coefficient of horizontal mirror.

Since K_g and K_s must, of necessity, be obtained together, we have as the required transmission coefficient for the θ sector

$$K_g K_s = \frac{K_0 K_g \sin \theta}{K_e}$$

This value was computed for each sector and the glass smoked accordingly. It will be seen from this that the intensities are cut down as a whole in the ratio $K_0 K_g : 1$, and furthermore, separately in the ratio $\sin \theta : 1$.

The mirrors were paired and put in position according to the following table:

TABLE III.

Position of Mirrors.

Position.	Mirrors.	Mean Constant at 40°
0	6 and 7	.812
15A	22 " 24	.812
30A	9 " 14	.832
45A	15 " 19	.798
60A	11 " 12	.837
75A	1 " 5	.793
15B	20 " 21	.812
30B	16 " 17	.818
45B	2 " 23	.830
60B	10 " 18	.809
75B	3 " 8	.803

Constant of Mirror behind Photometer at 12½° = .901.

Some care and skill are necessary to produce a uniform coating of smoke of just the required density. I have found it convenient to use a sheet iron chamber, fitted with a suitable flue, and pierced near the top with a small opening for the introduction of the glass. This chamber must be placed near one end of the photometer bar in order that the absorption of the glass may be tested as frequently as may be necessary. The setting of the photometer being predetermined, each sector is smoked until it shows the required absorption. There is a tendency for the coating to form most heavily near the edges of the glass. This may

be overcome by providing a guard ring of glass of the same thickness as the piece to be smoked, the whole being mounted in a convenient holder. The best results will be obtained by holding the piece of glass vertically in the smoke chamber, occasionally reversing the piece. Turpentine is a good combustible, but it must be introduced into the receptacle at the base of the chamber in small quantities, otherwise the combustion will be so violent as to produce a flocculent deposit on the glass.

In testing the glasses it is best to use a small source of light, such as a narrow slit in front of a straight filament glow-lamp. Any inequalities in the coating of smoke can be detected by moving the glass about in front of this opening, care being taken that the same plane is maintained. It will be seen in Fig. 2 that the incidence of the light upon the glass is not quite normal. Care was taken to maintain this same incidence in the absorption tests.

At M_s is shown a mirror for directing the light from the temporary standard to the photometer. This mirror might have been omitted had not the limits of the photometer room already been taxed to the utmost. Still better, if the mirrors were from one large piece of glass, the direction of the photometer bar might be such that the same incidence would be had on M_s as upon the others. In this case, the correction for the mirror absorption would be eliminated.

The illumination upon the arc side of the photometer screen is, of course, very intense. It is necessary to reduce this illumination. For this purpose, I have used a rotating wheel w, provided with a large number of narrow radial slots. It is quite essential that the number of open slots should be large, as otherwise the illumination on the photometer screen will be seen to beat or pulsate when measurements are being made on the alternating arc. In order to avoid the error found by Ferry[1] I have determined the constant of this wheel by direct experiment on the arc itself, and not by calculation. The mean of several determinations gives

$$\text{Transmission constant sectored wheel} = K_w = .090$$

The number of slots in this wheel is 48, which gives a frequency amply great at the normal speed of the motor used for driving the wheel.

1. *Physical Review*, vol. i, p. 338.

A possible source of error is the diffusion of the smoked glass disk. That is to say, since the disk receives a certain flux of light dependent upon the solid angle which it subtends from each image as a center and upon the intensity of such image, it becomes, to some extent, a secondary source. The direct measurement of this is a matter of some difficulty. To determine if the correction for this diffusion were of importance, I proceeded as follows: The longitudinal screen ss' was removed, the mirrors to the left of the vertical were covered, and likewise the right half of the sectored glass disk. With an arc of ordinary intensity in the center of the mirror system, it is evident that the left half of the sectored disk receives a flux of light about equal to that which it would normally receive with the longitudinal screen in position and the mirrors entirely uncovered. At the same time, no direct light from the images falls upon the photometer screen. Any illumination perceived under such circumstances would be due to the diffusive action of the glass. As a matter of fact, I found that with the temporary standard stopped down by a narrow slit, I could get a setting in this way when the sectored wheel was not in position, but when this wheel was running in its proper place the correction was entirely negligible. Hence no further attempt was made to take account of it.

The distance from source to photometer screen is large, being nearly nine metres. As the incidence of the light from the temporary standard is the same as that from the arc, no correction is here necessary.

A working equation may be developed as follows: Let

d_a = distance from arc to photometer screen.
d_s = distance from temporary standard to photometer screen.
K_0 = reflection constant of the horizontal mirror.
K_g = transmission constant of clean glasses.
K_s = reflection constant of mirror on glow lamp side.
K_w = transmission constant of wheel.
n, n' = number of mirrors.
f = factor due to the lack of normal incidence.

The illumination due to the arc is

$$i = \frac{2 K_0 K_g K_w f \sum_0^{\pi} I_\theta \sin \theta}{d_a^2}$$

and that due to the standard of intensity I_s

$$i_s = \frac{f K_s I_s}{d_s^2}$$

Equating these two expressions, we have for the mean spherical intensity

$$I_{ms} = \frac{\pi}{2n} \sum_0^{\pi} I_\theta \sin\theta$$

$$= \frac{\pi K_s}{4 n K_0 K_g K_w} \left(\frac{d_a}{d_s}\right)^2 I_s$$

Similarly for the mean hemispherical

$$I_{mhs} = \frac{\pi}{2n'} \sum_0^{\pi/2} I_\theta \sin\theta$$

$$= \frac{\pi K_s}{4 n' K_0 K_g K_w} \left(\frac{d_a}{d_s}\right)^2 I_s$$

With the following numerical values

$$d_a = 865 \text{ cm.} \qquad n = 12$$

$$n' = 7$$

$$K_0 = .812 \qquad K_s = .901$$

$$K_g = .690 \qquad K_w = .090$$

These equations reduce to

$$I_{ms} = 1.17 \left(\frac{865}{d_s}\right)^2 I_s$$

$$I_{mhs} = 2.01 \left(\frac{865}{d_s}\right)^2 I_s$$

which are the working equations for the apparatus. Values of d_s are recorded on a drum in a manner already described by the writer.[1] (See Fig. 2.)

Values of $\left(\frac{d_a}{d_s}\right)^2$ are obtained by laying a graduated T-

1. *Physical Review*, vol. vii, p. 239, 1898.

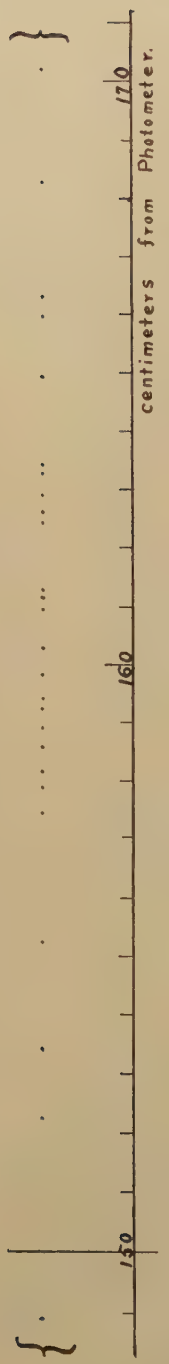

FIG. 5.—Specimen Record from Recording Drum.

square on the records obtained on the recording drum. A single covering on the drum suffices for the record of many tests. The records may then be worked out at the leisure of the operator. These records have always the same general characteristics, namely, many settings close together with scattered settings at each end. Figure 5 is a specimen record, and shows the usual range of fluctuation. The number of settings here is 30. This large number is necessary because of the fluctuations in the intensity of the arc, even with the steadying effect peculiar to the multiple mirror method. With hand fed arcs, a smaller number will suffice to give a value representative of the average performance of the arc. For the distribution curves, it suffices to uncover the mirrors in pairs and make settings in the usual way. The appropriate mirror constants must, of course, be used in working up the results.

As a check on the accuracy of the integrating method as compared with the usual method, I give the results of a test on an arc of the enclosed type. The value obtained from the Rousseau diagram is 308. That by the method described in this paper, 319. This agreement is within 3.4 per cent. When one considers the difficulty in maintaining an automatic feed arc under constant conditions during the time required to take the distribution curve, this must be considered as a very satisfactory agreement.

APPENDIX.

The product of the intensity I and the area of an elementary zone of radius r is

$$I_\theta \, d\, S = I_\theta \times 2\, \pi\, r\, R\, d\, \theta$$

$$= 2\, \pi\, R^2\, I_\theta \sin \theta\, d\, \theta.$$

The mean spherical intensity is

$$I_{ms} = \frac{\int I_\theta \, d\, S}{4\,\pi\, R^2} = \tfrac{1}{2} \int_0^\pi I_\theta \sin\theta \, d\,\theta$$

The graphic method due to Rousseau is shown in Fig. 6. $\overline{O\,a\,b}$ is the given distribution. Draw a semi-circle of convenient radius. Project on the vertical $c\,d$ the points h, k. At f, g, lay off the corresponding intensities I_1, I_2. The area $\overline{c\,m\,n\,p\,d}$

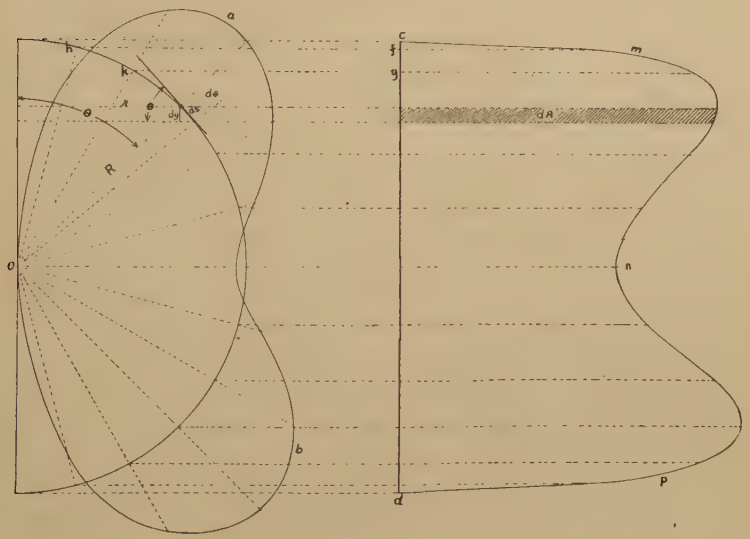

Fig. 6.

may be taken with a planimeter. This area divided by the base $\overline{c\,d}$ gives the mean spherical intensity, for

$$d\,\theta = \frac{d\,s}{R}$$

$$d\,s \sin\theta = d\,y$$

$$I_{ms} = \frac{1}{2\,R} \int_0^{2R} I_\theta \, d\,y = \frac{A}{2\,R}.$$

PART IV.

THE LIFE AND EFFICIENCY OF COMMERCIAL BRANDS OF CARBONS FOR INCLOSED ARCS.

PART IV.

THE LIFE AND EFFICIENCY OF COMMERCIAL BRANDS OF CARBONS FOR INCLOSED ARCS.

In this part of the work the apparatus described in Part III has been used.

PRELIMINARY TEST.

In order to ascertain the behavior of the apparatus on an actual life test, several preliminary runs were made. Two of the most characteristic of these are selected for presentation here. A 110 volt, constant-potential, alternating-current lamp, with shade and opalescent inner globe (being, in fact, one of the lamps used in the subsequent test), was tested at intervals of about ten hours during its life. The results obtained are to be found in Table I and Figure 7.

The first point was discarded because of uncertain conditions, but otherwise the curve is fairly indicative of the behavior of such a lamp. The arc appears beneath the shade between the fourth and fifth tests. This event is accompanied by a rise in the curve, due to the strengthening of the horizontal intensity. This effect will be noticed in most of the curves to follow.

TABLE I

Test	Time	Intensity
1	2.6 Hours	273 H. U.
2	12.8 "	249 "
3	22.1 "	237 "
4	33.5 "	236 "
5	45.5 "	251 "
6	56.1 "	233 "
7	66.8 "	233 "
8	76.9 "	200 "

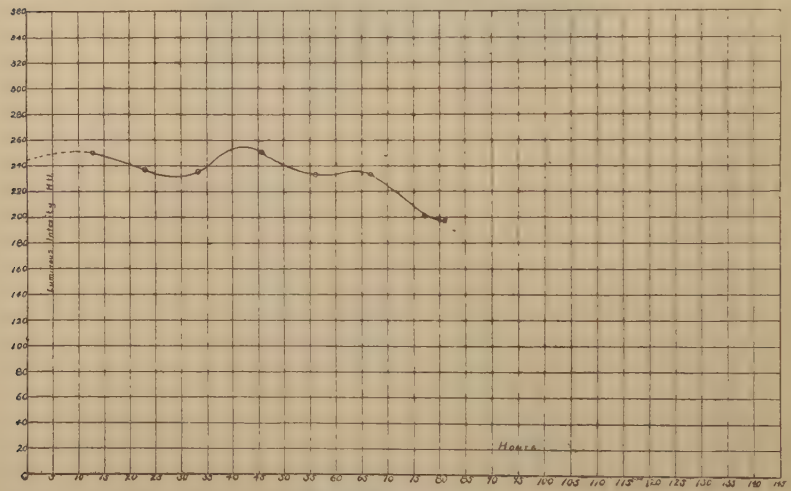

FIG. 7.—LIFE TEST, SHOWING MEAN HEMISPHERICAL INTENSITY FOR 110-VOLT, CONSTANT-POTENTIAL, ALTERNATING-CURRENT LAMP WITH SHADE.

Then comes a dip followed by a second maximum. The arc is now about midway between the bottom of the shade and the base of the globe. This appears to be a very effective position. But, after this, the arc is descending into a region of the globe more or less heavily coated with ash and carbon dust, and the decline in intensity up to the point of extinction is rapid.

In a life history like this we have probably many minor influences that cannot be taken into consideration, but undoubtedly the prime causes for the observed changes in intensity are (1) the descending arc, and (2) the formation of a globe coating. These influences are, much of the time, opposing ones. The resultant effect, as shown in the later curves of this report, will be modified according to the predominance of one or the other influence.

An inspection of the inner globes shows that the coating forms most heavily in two regions. Near the top of the globe is a zone of cream-colored ash, quite free from carbon dust. This zone follows the arc in its downward course, but always with a diminishing thickness of the deposit. While there may be a considerable loss of light because of this formation, the increasing available light flux due to the descending arc may oftentimes overcome it, especially in the case of alternating lamps with wide, dark surfaces above the globe. (See the preceding report.) Near the bottom of the globe is a zone of ash lighter in color than that at the top. Mixed with this ash is a considerable amount of carbon dust. The amount of this dust is dependent upon the steadiness of operation of the lamp. If the lamp feeds frequently, or if the carbons chatter, this deposit will be found heavier than usual.

TABLE II

Test	Time	Intensity
1	5.2 Hours	140 H. U.
2	16.3 "	130 "
3	23.3 "	120 "
4	33.6 "	118 "
5	44.9 "	123 "
6	55.- "	123 "
7	66.6 "	125 "
8	76.8 "	107 "
9	87.1 "	114 "

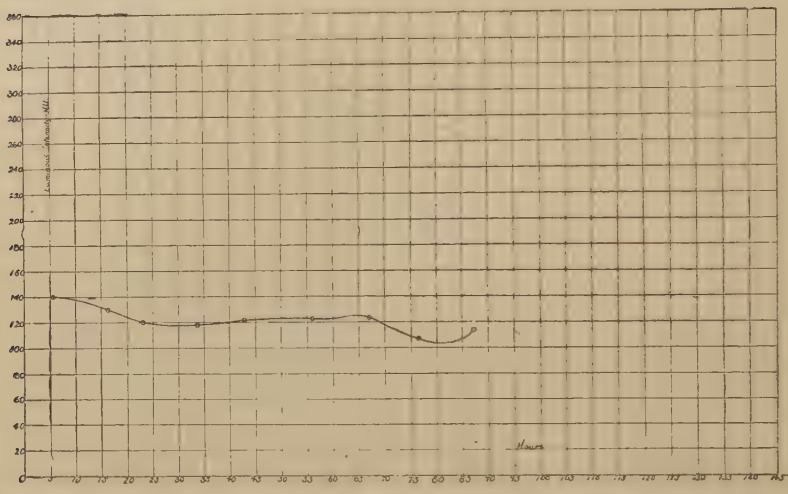

FIG. 8.—LIFE TEST, SHOWING MEAN SPHERICAL INTENSITY OF 110-VOLT, CONSTANT-POTENTIAL, ALTERNATING-CURRENT LAMP WITH DIFFUSING SHADE.

In Table II and Figure 8 are to be found the results of a second preliminary run. This lamp was of the same type as that just mentioned, except that the shade was replaced by an opal spherical globe. The ordinates of the curve are here the mean spherical intensity. As would be expected, this type shows but little change. The globe itself is the chief source of light, and the position of the arc in it has only a secondary effect. The downward trend of this curve must be due to the coating.

LIFE AND EFFICIENCY OF COMMERCIAL BRANDS OF CARBONS

The preliminary measurements just described indicated that the photometric apparatus would adequately answer the purpose for which it was designed. Preparations were therefore made to test samples of five brands of carbons for inclosed-arc lighting, these brands being well known and obtainable in the open markets of to-day. The samples represent the product of three American and two European manufacturers.

The carbons were burned in six 110-volt, alternating-current lamps, provided with opalescent inner globes and shades. (See Figure 4.) Of these lamps, five were fitted with the particular brand of carbons to be tested, the sixth lamp being held in reserve, lest accident or poor operation should require a substitution. Experience showed, in one or two cases, the wisdom of this precaution. The lamps were suspended from the radial arms of the wheel shown in the foregoing plan of the apparatus. In this position, the lamps ran out the life of one trimming. With few exceptions, the only stops were at the close of the laboratory day. Counting all interruptions, the average run was about eight hours. Not infrequently, a steady run of twelve hours occurred. These conditions are probably somewhat better, and certainly no worse, than the average conditions of practice. The carbon life shown in the following results seems to corroborate this statement, as the life usually claimed for lamps of this type is eighty to one hundred hours. It may be well to note just here that the duration of burning in these lamps is limited by the allowable range of descent of the upper carbon holder. This range is a fixed quantity.

The life on one trimming may therefore be expressed by the simple formula,

$$t = \frac{l_o}{r_u + r_l}$$

where l_o is the fixed range referred to and r_u, r_l the respective rates of burning of the upper and lower carbons. The life, clearly, will be a maximum for that case in which the sum of these rates is a minimum.

A lamp fitted with a shade is in itself an intimation that only the downward flux of light is of value. The logical basis of comparison in such cases is the mean hemispherical intensity, or, if desired, the downward *flux* of light, which is $2\pi \times$ the mean hemispherical intensity. In the following carbon tests, the mean hemispherical intensity is the quantity determined. In the curves it will be found plotted as an ordinate against time as an abscissa.

In what follows, the brands of carbons will be designated by Roman numerals, I, II, etc., in the order of the tests, while the lamps will be referred to as A, B, etc. The upper carbon in all the tests was cored, the lower carbon solid.

Carbons I. The results of the first test are to be found in tables III and IV. Figure 9 shows the life curves of the individual lamps in thin lines and the mean performance of the five lamps in the thick line. We note here that the trend of the mean curve is, in the main, upward. After eighty-five hours' burning, the lamps show ten per cent better performance than at the start. The mean curve has the same general shape as the preliminary curve (Figure 7). Lamp B distanced its companions by showing a life of 114 hours. On the third, fourth, seventh and eighth tests

the points are quite close together; on the other tests there is more or less divergence. Why this difference? The use of an apparatus for recording the changes in the arc length in lamps such as these has convinced

TABLE III

CARBONS I

Lamp A

Test	Time	Intensity
1	3.2 Hours	202 H. U.
2	13.7 "	222 "
3	23.1 "	193 "
4	33.2 "	196 "
5	46.8 "	202 "
6	54.3 "	173 "
7	63.9 "	202 "
8	74.0 "	214 "
9	84.6 "	200 "
10	92.6 "	189 "

Lamp B

1	3.3 Hours	194 H. U.
2	13.7 "	170 "
3	23.2 "	179 "
4	33.0 "	194 "
5	44.2 "	205 "
6	54.2 "	198 "
7	63.7 "	212 "
8	73.8 "	222 "
9	84.4 "	231 "
10	95.7 "	184 "
11	111.0 "	187 "
12	114.3 "	152 "

Lamp C

1	3.4 Hours	217 H. U.
2	14.0 "	204 "
3	23.2 "	187 "
4	33.0 "	188 "
5	44.2 "	213 "
6	54.1 "	229 "
7	63.5 "	203 "
8	73.6 "	221 "
9	84.2 "	207 "
10	94.2 "	162 "

TABLE III—*Continued.*

Lamp D		
1	3.3 Hours	223 H. U.
2	14.0 "	217 "
3	23.5 "	190 "
4	33.2 "	194 "
5	44.5 "	231 "
6	54.4 "	207 "
7	63.8 "	211 "
8	73.8 "	213 "
9	84.4 "	251 "
10	95.8 "	188 "
Lamp E		
1	3.6 Hours	176 H. U.
2	14.2 "	186 "
3	23.8 "	173 "
4	33.3 "	187 "
5	44.6 "	200 "
6	54.5 "	228 "
7	63.8 "	201 "
8	73.9 "	220 "
9	84.5 "	216 "
10	95.9 "	177 "
11	97.1 "	167 "

me that these differences are due in a large measure to changes in the arc length. Now, the time between successive feedings is, in a well regulated lamp, an interval considerably longer than that required for a test. During this interval between feedings, the arc tends to grow steadily longer. It has been shown by Blondel and by Ayrton that the luminous intensity of an arc at constant current is dependent, in a very important way, on the arc length. It seems clear, then, that tests such as those described here might at one time find the arcs of approximately the same length, and at another time differing considerably in length. Lack of homogeneity in either upper or lower carbon might also have an effect. It is evident that any constant difference in the carbons or in the transparency of the inner globes would be made manifest by a permanent separation of the life curves.

TABLE IV

CARBONS I

Lamp	A	B	C	D	E	Mean
Inner globe, initial weight, grammes	88.300	79.557	86.101	84.384	86.972	
Inner globe, final weight, grammes	88.495	79.745	86.301	84.587	87.131	
Inner globe, gain weight, grammes	.195	.188	.200	.203	.159	.189
Carbons						
Initial weight, upper, grammes	45.174	45.372	45.150	44.204	47.984	
Final weight, upper, grammes	31.865	32 157	31.562	30.032	35.057	
Consumption, upper, grammes	13.309	13.215	13.588	14 172	12.927	13.442
Initial weight, lower, grammes	25.665	25.872	27.060	27.074	25.585	
Final weight, lower, grammes	10 330	9 830	11.280	12.571	9.134	
Consumption, lower, grammes	15.335	16.042	15.780	14.503	16.451	15.662
Initial length, upper, inches	9.53	9.52	9.54	9.51	9 54	
Initial length, upper, centimeters	24.21	24.18	24.23	24.15	24 23	
Initial length, lower, inches	5.77	5.75	5.82	5.80	5.78	
Initial length, lower, centimeters	14.65	14.60	14.78	14.73	14.68	
Total consumption, grammes	28.644	29.257	29.368	28.675	29.378	29.064
Total consumption, inches	6.18	6.27	6.25	6.16	6.12	
Total consumption, centimeters	15.70	15.92	15.87	15.64	15.54	
Consumption ratio	15.2%	21.3%	16.1%	2.3%	27.2%	16.4%
Per cent of ash and dust	.68%	.64%	.68%.	.70%	.54%	.65%
Diameter of upper, inches	.510	.514	.512	.515	.514	.513
Diameter of upper, centimeters	1.295	1.305	1.300	1.308	1 305	
Clearance, inches	.011	.009	.010	.008	009	.0094
Clearance, centimeters	.028	.023	.025	.02	.023	.024
Number of extinctions	10.	12.	10.	11.	11.	11.
Average run	9.2	9.5	9.4	8.8	9.4	9.3
Voltage	110.	110.	110.	110.	110.	
Current, mean	6.0	6.1	6.3	6.1	6.0	
Power in lamp	429.	430.	452.	440.	422.	435.
Mean watts per H. U	2.1	2.2	2.2	2.1	2.1	2.14
Power factor of lamp	.65	.64	.65	.65	.64	
Life of one trimming, hours	92.2	114.0	94.3	97.1	102.9	100.1
Life per inch carbon, hours	14.9	18.2	15.1	15.8	16.8	16.2
Life per centimeter carbon, hours	5.9	7.2	5.9	6.2	6.6	6.4
Life per gramme carbon, hours	3.2	3.9	3.2	3.4	3.5	
Luminous intensity, H. U	200.	197.	204.	213.	197.	202
H. U. hours of lamp	18,400.	22,400.	19,200.	20,700.	20,300.	20,200.
H. U. hours per inch	2,984.	3,576.	3,081.	3,358.	3,316.	3,263.
H. U. hours per centimeter	1,174.	1,407.	1,213.	1,323.	1,305.	1,284.

While the length of these curves indicates the life of the carbons and the mean ordinate their light value, these quantities alone are not a sufficient measure of the worth of the carbon. The area between the curves and the X-axis is an important basis of comparison. This area has been found for each test. It is measured in Hefner-unit-hours. For Carbons I this quantity is 20,200 or 202 *hecto-Hefner-hours*. The mean intensity is 202 Hefner units, and the life on one trimming 100

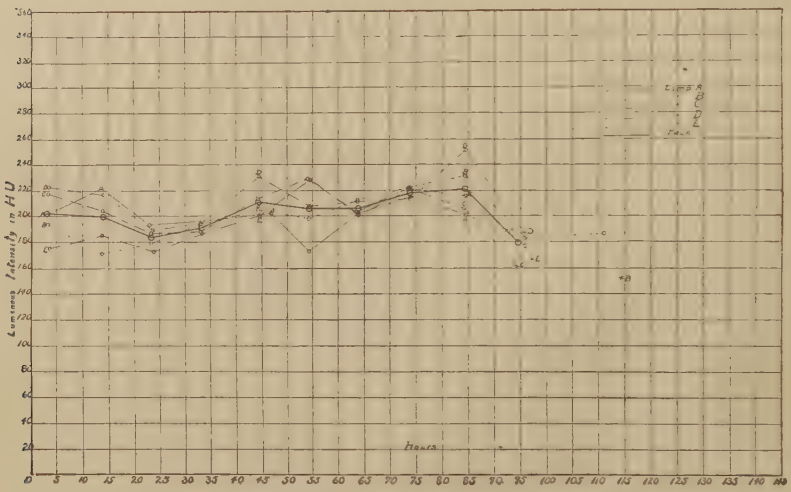

FIG. 9.—INTENSITY LIFE TESTS OF CARBONS I.

hours. To eliminate the lamp from the problem, the table shows the Hefner-unit-hours per unit length of carbon consumed and also per unit mass consumed,* which last leaves the dimensions of the carbon out of the question. These matters will be more fully discussed in the final summing up of the tests.

Carbons II. The records for this set of carbons are to be found in Tables V and VI and in Figure 10. The mean life is practically ninety-nine hours.

*To facilitate comparison with other results, I have used both centimeter and inch units.

However, Lamp A showed the brief life of 62.5 hours. There must have been some imperfection in the fit of the gas cap, although every precaution was taken to secure impartial treatment in this as in every other respect. If it is justifiable to exclude A, we find

TABLE V

CARBONS II

LAMP A

Test	Time	Intensity
1	1.0 Hours	157 H. U.
2	11.8 "	238 "
3	21.7 "	228 "
4	32.0 "	209 "
5	42.2 "	209 "
6	52 3 "	221 "
7	62.5 "	219 "

LAMP B

1	1.1 Hours	240 H. U.
2	8.3 "	203 "
3	17 9 "	218 "
4	28.2 "	220 "
5	38.3 "	219 "
6	49 4 "	215 "
7	60.0 "	232 "
8	69.8 "	233 "
9	81.8 "	241 "
10	91.7 "	243 "
11	103.2 "	193 "

LAMP D

1	1 1 Hours	187 H. U.
2	12.0 "	192 "
3	21.6 "	188 "
4	31.9 "	203 "
5	42 0 "	203 "
6	52.0 "	216 "
7	62.5 "	203 "
8	72.3 "	230 "
9	84.2 "	205 "
10	94.1 "	203 "
11	108.4 "	181 "

TABLE V—*Continued.*

LAMP E

1	2.2 Hours	217 H. U.
2	12.8 "	224 "
3	23.9 "	220 "
4	34 3 "	214 "
5	45.7 "	227 "
6	56.7 "	233 "
7	66.4 "	252 "
8	76.4 "	213 "
9	86.8 "	174 "
10	97.9 "	158 "

LAMP F

1	1.3 Hours	213 H. U.
2	12.2 "	239 "
3	22.0 "	258 "
4	32.5 "	244 "
5	42.6 "	258 "
6	52.7 "	239 "
7	63.2 "	263 "
8	73.0 "	230 "
9	85.0 "	241 "
10	94.9 "	218 "
11	109.1 "	209 "

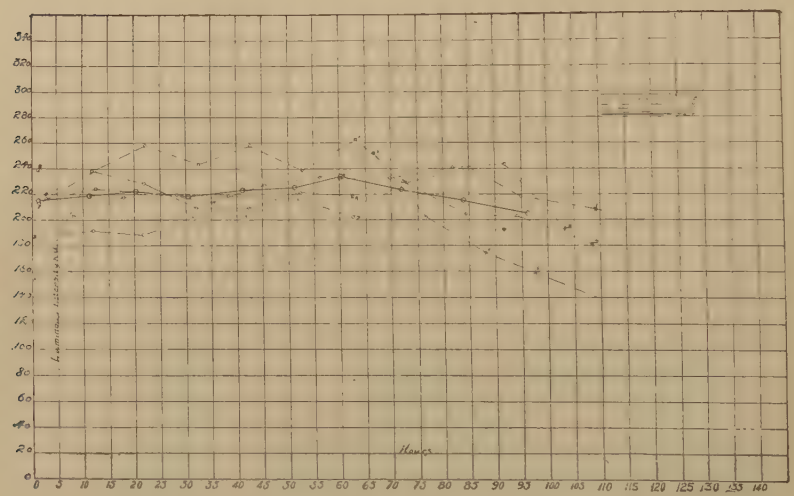

FIG. 10.—INTENSITY LIFE TESTS OF CARBONS II.

TABLE VI

CARBONS II

Lamp	A	B	D	E	F	Mean
Inner globe, initial weight, grammes	78.853	78.233	110.159	82.301	81.687	
Inner globe, final weight, grammes	78.990	78.399	110.327	82.447	81.885	
Inner globe, gain weight, grammes	.137	.166	.168	.146	.198	.150
Carbons						
Initial weight, upper, grammes	44.080	43.234	45.195	42.550	41.346	
Final weight, upper, grammes	30 308	29.546	32 469	31.112	28.255	
Consumption, upper, grammes	13.772	13.688	12.726	11.438	13.091	12.943
Initial weight, lower, grammes	26.180	26.141	26.629	24.130	26.350	
Final weight, lower, grammes	11.408	10.827	10 878	9.174	12.093	
Consumption, lower, grammes	14.772	15.314	15.751	14.956	14.257	15.010
Initial length, upper, inches	9.54	9.48	9.51	9.48	9.49	
Initial length, upper, centimeters	24.23	24 08	24.15	23.07	24.10	
Initial length, lower, inches	5.68	5.67	5.75	5 72	5.73	
Initial length, lower, centimeters	14.43	14.40	14.60	14.52	14.55	
Total consumption, grammes	28.544	29.002	28.477	25.476	27.348	27.769
Total consumption, inches	6.2	6.34	6.05	5 80	6.11	
Total consumption, centimeters	15.74	16.10	15.36	14.75	15.52	
Consumption ratio	7.2%	11.8%	23.7%	30.7%	8.9%	16.5%
Per cent of ash and dust	.48%	.57%	.59%	.57%	.72%	.59%
Diameter of upper, inches	.516	.511	.507	.509	.514	.511
Diameter of upper, centimeters	1.31	1.29	1.28	1.29	1.30	
Clearance, inches	.008	.011	.013	.011	.009	.010
Clearance, centimeters	.020	.027	.032	.027	.023	.026
Number of extinctions	8.	13.	13.	25.	13.	14.
Average run	7.8	7.9	8.3	4.4	8.6	7.4
Voltage	110.	110.	110.	110.	110.	
Current, mean	6.2	6.2	6.2	6.3	6.4	
Power in lamp	448.	436.	434.	414.	441.	435.
Mean watts per H. U.	2.10	1.90	2 15	1.95	1.85	1.99
Power factor of lamp	.65	.64	.63	.60	.62	
Life of one trimming, hours	62.5	103.2	108.3	108.9	111.2	98.8
Life per inch carbon, hours	10.1	16.3	17.9	18.6	18.2	16.2
Life per centimeter carbon, hours	3.9	6.4	7.1	7.3	7.2	6.4
Life per gramme carbon, hours	2.2	3.6	3.8	4.3	4.	
Luminous intensity, H. U.	213.	223.	202.	212.	238.	218.
H. U. hours of lamp	13,300.	23,000.	21,900.	23 100.	26,400.	21,500.
H. U. hours per inch	2,147.	3,633.	3,612.	3,986.	4,324.	3,540.
H. U. hours per centimeter	845.	1,430.	1,422.	907.	1,702.	1,261.

a life of 107.9 hours. The Hefner-unit-hours rise in such case to 23,800. The performance of A indicates that the life of an inclosed arc may be seriously curtailed by causes not easily detected.

The mean curve in this test rises to a maximum at sixty hours' life. Lamp F shows a somewhat remarkable performance both as regards intensity and life. A mean intensity of 238 Hefner units is maintained throughout 111 hours, or a yield of 264 hecto-Hefner-hours, which is about double the yield of A.

Carbons III. The records for this set of carbons are to be found in Tables VII and VIII and in Figure 11. As regards life, these carbons show a

TABLE VII

CARBONS III

LAMP A

Test	Time	Intensity
1	3.4 Hours	211 H. U.
2	21.9 "	220 "
3	34.0 "	223 "
4	44.2 "	219 "
5	54.1 "	218 "
6	63.7 "	208 "
7	73 6 "	184 "
8	84.0 "	198 "
9	98.6 "	199 "
10	108.6 "	224 "
11	118.2 "	183 "

LAMP B

1	3.5 Hours	259 H. U.
2	21.9 "	239 "
3	34.0 "	224 "
4	44.2 "	239 "
5	54.1 "	231 "
6	63.6 "	229 "
7	73.5 "	205 "
8	83.9 "	219 "
9	98.5 "	195 "

TABLE VII—*Continued.*

LAMP D

1	3.6 Hours	207 H. U.
2	22.7 "	219 "
3	34.6 "	227 "
4	44.8 "	233 "
5	54.7 "	228 "
6	63.2 "	232 "
7	73.1 "	234 "
8	83.5 "	202 "
9	98.3 "	217 "
10	108.2 "	245 "
11	118.3 "	183 "
12	128.6 "	230 "

LAMP E

1	3.6 Hours	234 H. U.
2	22.9 "	248 "
3	34.8 "	238 "
4	45 0 "	241 "
5	55.0 "	236 "
6	64.5 "	233 "
7	74.1 "	192 "
8	84.5 "	221 "
9	99.1 "	203 "
10	109.0 "	223 "
11	114.0 "	199 "

LAMP F

1	3.7 Hours	235 H. U.
2	22.2 "	253 "
3	34.2 "	250 "
4	44 5 "	250 "
5	54 3 "	235 "
6	63.8 "	238 "
7	73 6 "	221 "
8	84.0 "	221 "
9	98.7 "	211 "
10	108.5 "	216 "
11	117.7 "	149 "

noteworthy performance. The mean life is 115.6 hours, and the maximum life 129 hours. The mean curve does not show the tendency to rise shown in the case of Carbons I, although as a whole it lies high. By weight, the per cent ash and dust is about the same. An inspection of the inner globes after the tests showed that the deposit near the base of

TABLE VIII

CARBONS III

Lamp	A	B	D	E	F	Mean
Inner globe, initial weight, grammes	73.479	68.960	90.980	75.452	82 867	
Inner globe, final weight, grammes	73.657	69.136	91.171	75.640	83.064	
Inner globe, gain weight, grammes	.178	.176	.191	.188	.197	.186
Carbons						
Initial weight, upper, grammes	44.736	44.077	43.377	44.504	43.693	
Final weight, upper, grammes	30.338	29.480	29 617	30.694	29.978	
Consumption, upper, grammes	14.398	14.597	13.760	13.810	13 715	14.056
Initial weight, lower, grammes	28.504	28 280	27.265	27.260	27.203	
Final weight, lower, grammes	13.873	13.515	12.08	12.634	12 641	
Consumption, lower, grammes	14.631	14.765	15.184	14.626	14.652	14.772
Initial length, upper, inches	9.53	9.52	9.52	9.52	9.51	
Initial length, upper, centimeters	24.20	24.18	24.18	24 18	24.15	
Initial length, lower, inches	5.76	5.82	5 82	5.82	5.81	
Initial length, lower, centimeters	14.63	14.78	14 78	14 78	14.75	
Total consumption, grammes	29.029	29.362	28.944	28 436	28.367	28.828
Total consumption, inches	6.07	6.23	6.29	6.08	6.12	
Total consumption, centimeters	15.42	15.82	15.07	15 44	15.54	
Consumption ratio	1.6%	1.1%	10.3%	5.8%	6.8%	5.1%
Per cent of ash and dust	.60%	.59%	.65%	.66%	.69%	.64%
Diameter of upper, inches	.513	.513	.513	.513	.515	.5134
Diameter of upper, centimeters	1.303	1.303	1.303	1.303	1.308	
Clearance, inches	.0095	.0095	.0095	.0095	.0085	.0093
Clearance, centimeters	.0241	.0241	.0241	.0241	.0215	.0236
Number of extinctions	16.	14.	18.	16.	16.	16.
Average run, hours	7.47	7.03	6.54	7.12	7.27	7.09
Voltage	110.	110.	110.	110.	110.	
Current, mean	6.2	6.17	6.21	6.06	6.28	
Power in lamp	423.	436.	421.	430.	441.	430.
Mean watts per H. U	2.02	1.92	1.91	1.91	1.91	1.934
Power factor of lamp	.62	.55	.62	.55	.56	
Life of one trimming, hours	118.6	98.4	128.6	114 1	118.3	115.6
Life per inch carbon, hours	19.5	15.8	18.7	18.8	19.3	18.4
Life per centimeter carbon, hours	7.7	6.2	7.4	7.4	7.6	7.3
Life per gramme carbon, hours	4.1	3.4	4.1	4.	4.2	
Luminous intensity, H. U	209.	226.	220.	225.	231.	222.
H. U. hours of lamp	24,700.	22,300.	25,900.	25,700.	27,300.	25,200.
H. U. hours per inch	4,063	3,571.	4,123.	4,230.	4,456.	4,089.
H. U. hours per centimeter	1,629.	1,406.	1,623.	1,665.	1,754.	1,615.

the globe in Case III was darker—that is, contained more carbon dust than in Case I. This is, in my opinion, the cause of the drooping tendency to be seen in the mean curve of Carbons III after forty-five hours. In this connection, it is important to note that the number of extinctions in these tests was

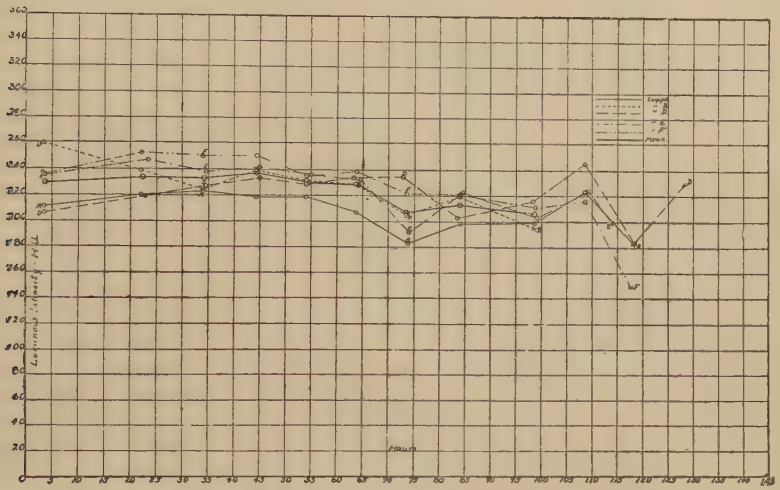

FIG. 11.—INTENSITY-LIFE TESTS OF CARBONS III

somewhat greater than in the case of Carbons I and II. The carbon dust is due, in large part, to the pounding or chattering of the carbons at the start.

These carbons show a mean performance of 252 hecto-Hefner-hours.

Carbons IV. The records for this brand of carbons can be found in Tables IX and X, while the life curves are to be seen in Figure 12. The mean life curve is an exceptionally good one and shows in a very satisfactory manner the changes that occur in the luminous intensity of a lamp of this type during its carbon life.

These carbons show a superior luminous intensity coupled with long life. A mean intensity of 259

TABLE IX

CARBONS IV

LAMP A

Test	Time	Intensity
1	4.42 Hours	239 H. U.
2	14.9 "	259 "
3	25.4 "	241 "
4	35.6 "	228 "
5	49.0 "	250 "
6	62 8 "	274 "
7	79.8 "	253 "
8	91.9 "	242 "
9	102.3 "	238 "
10	117.5 "	271 "

LAMP B

Test	Time	Intensity
1	4.5 Hours	254 H. U.
2	15 0 "	264 "
3	25.5 "	264 "
4	35.7 "	236 "
5	49.0 "	272 "
6	63.1 "	268 "
7	79.9 "	278 "
8	91.9 "	253 "
9	102.3 "	260 "
10	108.8 "	225 "

CARBONS IV

LAMP B

Test	Time	Intensity
1	4.6 Hours	303 H. U.
2	15.0 "	340 "
3	25 5 "	278 "
4	35.5 "	272 "
5	49.1 "	301 "
6	62.9 "	278 "
7	80.0 "	349 "
8	85.6 "	231 "

TABLE IX—*Continued*

Lamp E

Test	Time	Intensity
1	4.7 Hours	224 H U.
2	15.1 "	262 "
3	25.5 "	241 "
4	35.8 "	263 "
5	48.4 "	264 "
6	63.2 "	269 "
7	80.1 "	277 "
8	92.1 "	260 "
9	102.4 "	244 "
10	109.5 "	252 "

Lamp F

Test	Time	Intensity
1	4.8 Hours	249 H U..
2	15.2 "	271 "
3	25.6 "	259 "
4	35.7 "	285 "
5	49 2 "	275 "
6	63.1 "	274 "
7	80.0 "	249 "
8	93.0 "	223 "
9	102 3 "	276 "
10	111.6 "	207 "

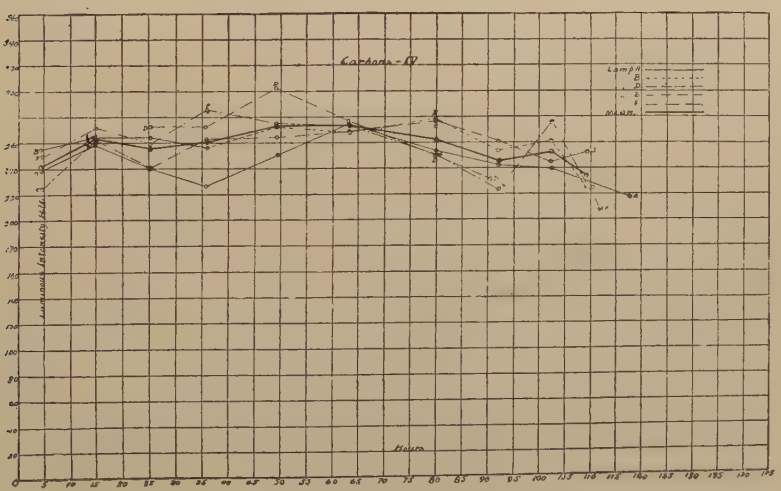

FIG. 12.—INTENSITY-LIFE TESTS OF CARBONS IV

TABLE X

CARBONS IV

Lamp	A	B	D	E	F	Mean
Inner globe, initial weight, grammes	79.474	82.424	67.872	67.997	72.147	
Inner globe, final weight, grammes	79.650	82.592	68.048	68 176	72.337	
Inner globe, gain weight, grammes	.176	.168	.176	.179	.190	.178
Carbons						
Initial weight, upper, grammes	40.032	40.411	40.941	41.110	39.470	
Final weight, upper, grammes	27.182	27.220	28.200	28.460	26.333	
Consumption, upper, grammes	12.850	13.191	12.741	12.650	13 137	12.913
Initial weight, lower, grammes	24.904	24.987	25.193	24.846	24 898	
Final weight, lower, grammes	11 400	10.448	10.868	10.790	11.339	
Consumption, lower, grammes	13.504	14.539	14.325	14.056	13.559	13.997
Initial length, upper, inches	9.53	9 53	9.55	9.54	9.54	
Initial length, upper, centimeters	24.20	24.20	24 25	24 23	24.23	
Initial length, lower, inches	5.77	5.80	5 77	5.80	5.78	
Initial length, lower, centimeters	14.65	14.73	14.65	14.73	14.68	
Total consumption, grammes	26.354	27.730	27.066	26.706	26 696	26.910
Total consumption, inches	6 19	6.50	6.26	6.20	6.35	
Total consumption, centimeters	15.72	16.51	15.90	15.73	16.12	
Consumption ratio	5.1%	10.2%	12.4%	11.0%	3.2%	8.4%
Per cent of ash and dust	.66%	.60%	.65%	.67%	.71%	.66%
Diameter of upper, inches	.517	.516	.517	.515	.516	.516
Diameter of upper, centimeters	1.315	1.310	1.315	1.308	1.310	
Clearance, inches	.0075	.008	.0075	.0085	.008	.0079
Clearance, centimeters	.019	.020	.019	.0215	.020	.0199
Number of extinctions	16.	15.	12.	15.	15.	15.
Average run, hours	7.34	7.26	7.13	7.30	7.46	7.3
Voltage	110.	110.	110.	110.	110.	
Current, mean	6.2	6.0	6.2	6.1	6 2	
Power in lamp	440.	453.	453.	463.	470.	456.
Mean watts per H. U	1.79	1.72	1.68	1.80	1.81	1.76
Power factor of lamp	.65	.69	.66	.69	.69	
Life of one trimming, hours	117.6	108.7	85.6	109.4	111.9	106.6
Life per inch carbon, hours	19.	16.7	13.7	17.6	17.6	16.9
Life per centimeter carbon, hours	7.5	6.6	5.4	7.	6.9	6.7
Life per gramme carbon, hours	4.5	3.9	3.2	4.1	4.2	
Luminous intensity, H. U	246.	262.	268.	257.	259.	259.
H. U. hours of lamp	28,900.	28,500.	22,800.	28,100.	29,000.	27,500.
H. U. hours per inch	4,665.	4,388.	3,638.	4,533.	4,569.	4,359.

Hefner-units is maintained throughout a life of some 106 hours—a yield of more than 275 hecto-Hefner-hours. At the same time, the individual lamp curves lie for the most part close together, indicating a uniformity of quality in the carbons.

Carbons V. Tables XI and XII and Figure 13 exhibit the results of the tests on this brand of carbons. The luminous intensity is seen to be relatively low and the life short. These carbons have cores of a very loose structure. When the upper carbon is a

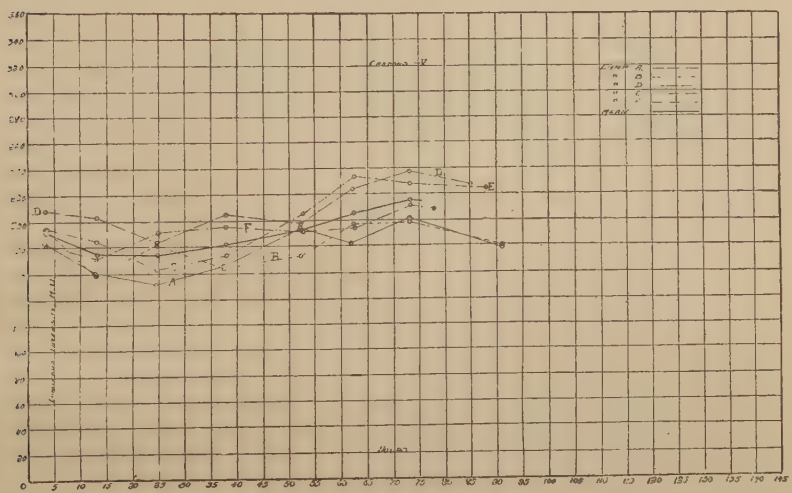

FIG. 13.—INTENSITY-LIFE CURVES OF CARBONS V

cored one, the material of the core for a considerable distance above the arc falls out under the feeding action of the lamp. Meanwhile an excessively long arc of low luminosity is drawn. The result was corroborated by taking autographic records of the operation of the lamps on an apparatus showing the fluctuations in the arc length. The mean life of these carbons is but eighty-six hours, and the mean intensity but 196 Hefner-units.

In Figure 14 the mean curves for the five brands

TABLE XI

CARBONS V

Lamp A

Test	Time	Intensity
1	3 1 Hours	184 H. U.
2	12.9 "	160 "
3	24.4 "	152 "
4	37.5 "	165.5 "
5	52.1 "	193 "
6	62.1 "	182 "
7	72.9 "	202 "
8	90 7 "	179 "

Lamp B

Test	Time	Intensity
1	3 1 Hours	192 H. U.
2	12.9 "	159 "
3	24.6 "	181 "
4	37.7 "	164 "
5	52.3 "	173 "
6	62.3 "	196 "
7	73.2 "	198 "
8	91 1 "	179 "
9	101.0 "	225 "

Lamp D

Test	Time	Intensity
1	3.2 Hours	208 H U.
2	13.0 "	203 "
3	24.7 "	183 "
4	57.2 "	204 "
5	52.4 "	193 "
6	62.2 "	223 "
7	73.0 "	237 "
8	85.1 "	227 "

Lamp E

Test	Time	Intensity
1	3.2 Hours	193 Hours
2	13.1 "	184 "
3	24.7 "	163 "
4	37.8 "	174 "
5	52.5 "	205 "
6	62.5 "	233 "
7	73.2 "	227 "
8	87.9 "	224 "

TABLE XI—*Continued*

CARBONS V

LAMP F

Test	Time	Intensity
1	3.3 Hours	181 H. U.
2	13.1 "	172 "
3	24.8 "	191 "
4	37.8 "	195 "
5	52.6 "	191 "
6	62.5 "	193 "
7	73.5 "	211 "
8	77.6 "	209 "

of carbons are plotted on one sheet. The superiority of Brand IV in intensity is here made manifest. It is interesting to note that all of the four remaining brands came to about the same intensity after seventy-

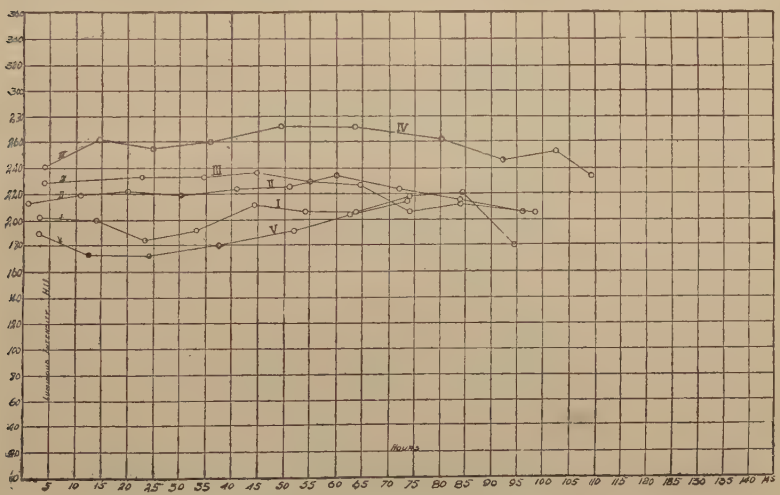

FIG. 14.—MEAN CURVE OF THE FIVE BRANDS OF CARBONS

five hours of life, although the divergence prior to this time is quite marked.

These brands of carbons may be compared in several ways. From a mere standpoint of life, the

order of merit is III, II, IV, I, V, the results on Lamp A being excluded from Carbons II (see page 23). That is to say, an American brand leads, followed by two European brands. Including Lamp A in Carbons II, the order is III, IV, I, II, V, the American Brand I rising to third place. From the standpoints of intensity and intensity x life, the order is IV, III, II, I, V. Here the European Brand IV has a distinct lead. The American Brand III lies in second place, closely followed by the second European Brand II.

The life per inch of carbon in these tests runs from 13.7 hours in the case of Brand V to 18.4 in the case of Brand III. The order of merit in this respect is the same as the life order given above.

First and Second Investigations—(*Continued*)

Owing to the growing importance of series arcs of the inclosed type, it has seemed very desirable to make a sufficient number of tests of both the direct-current and alternating-current lamps to get a measure of their relative worth. In Table XIII and in Figure 15 are embodied the results of a distribution test on a direct-current series lamp. This lamp is provided with opalescent inner and clear outer globes. The power consumption is 476 watts. With seventy volts at the terminals, it takes 6.8 amperes. It yields a mean spherical intensity of 266 Hefner units and a mean hemispherical intensity of 329 Hefner units. The curve is a very effective one for street lighting, as the intensity is strong between the horizontal and fifteen degrees below. If used for street lighting, such a lamp would be greatly improved by replacing the clear outer globe with a suitable shade.

TABLE XII

CARBONS V

Lamp	A	B	D	E	F	Mean
Inner globe, initial weight, grammes	77.279	77.788	84.725	73.463	84.625	
Inner globe, final weight, grammes	74.418	77.996	84.857	73 595	84.759	
Inner globe, gain weight, grammes	.139	.208	.132	.132	.134	.150
Carbons						
Initial weight, upper, grammes	41.182	40.867	41.295	40,714	41.584	
Final weight, upper, grammes	27.005	25.897	27 124	26.295	27.175	
Consumption, upper, grammes	14.177	14 97	14 171	14 419	14.409	14.429
Initial weight, lower, grammes	26.874	28 414	26.738	27.726	28.278	
Final weight, lower, grammes	13.151	14.546	12.827	14.156	14 179	
Consumption, lower, grammes	13.722	13.868	13 911	13.570	14 099	13.834
Initial, length, upper, inches	9.53	9.55	9.53	9.51	9.53	
Initial length, upper, centimeters	24.18	24.24	24.20	24.15	24.20	
Initial length, lower, inches	5.74	5.78	5.73	5.75	5.74	
Initial length, lower, centimeters	14.58	14.68	14.55	14.60	14.58	
Total consumption, grammes	27.899	28.838	28.082	27.989	28.508	28.263
Total consumption, inches	6.26	6.39	6.31	6 24	6.42	
Total consumption, centimeters	15.87.	16.23	15.97	15.85	15.82	
Consumption ratio	.4%	.8%	.2%	.6%	.3%	.5%
Per cent of ash and dust	.47%	.47%	.47%	.47%	.47%	.47%
Diameter of upper, inches	.501	.504	.501	.502	.501	.502
Diameter of upper, centimeters	1.27	1.28	1.27	1.27	1.27	
Clearance, inches	.0155	.0140	.0155	.0150	.0155	.0151
Clearance, centimeters	.039	.035	.039	.038	.039	.038
Number of extinctions	11.	13.	11.	11.	9.	11.
Average run, hours	8.2	8.1	7.7	7.9	6.9	7.7
Voltage	110.	110.	110.	110.	110.	
Current, mean	6.0	6.2	6.0	6.1	6.24	
Power in lamp	449.	458.	453.	455.	472.	457.
Mean watts per H. U.	2.5	2.5	2.2	2.3	2.2	2.3
Power factor of lamp	.62	.67	.62	.68	.68	
Life of one trimming, hours	90.8	101.5	85.2	87.9	62.5	85.6
Life per inch carbon, hours	14.5	15.9	13.5	14.1	10.3	13.6
Life per centimeter carbon, hours	5 7	6.2	5.3	5.5	4.1	5.3
Life per gramme carbon, hours	3.2	3.5	3.0	3.1	2.1	
Luminous intensity, H. U.	177.	183.2	207.	198.	212.	195.
H. U. hours of lamp	16,071.	18,594.	17,704.	17,422.	13,287.	16,613.
H. U. hours per inch carbon	2,567.	2,815.	2,805.	2,790.	2,069.	2,609.
H. U. hours per centimeter carbon	1,010.	1,108.	1,104.	1,098.	814	1,025.

The efficiency of this lamp is high, being 1.78 watts per mean spherical Hefner unit, and 1.41 watts per mean hemispherical Hefner unit.

In Table XIV and Figure 16 are embodied the results of a test on the series alternating-current lamp, provided with an opalescent inner globe and a metallic shade. A small reading is possible at fifteen degrees

TABLE XIII

D. C. SERIES

LAMP 67

Angle	Intensity
75° A	
60° A	48 H. U.
45° A	117 "
30° A	246 "
15° A	302 "
Hor.	348 "
15° B	372 "
30° B	371 "
45° B	364 "
60° B	229 "
75° B	150 "

Globes	Clear Outer Opalescent Inner
E. M. F.	70 volts
Current	6.8 amperes
Watts	476.
Mean hemispherical Intensity, H. U.	329.
Mean spherical Intensity, H. U.	266.
Watts per mean spherical, H. U.	1.78
Watts per mean hemispherical, H. U.	1.41

above, but above this point no light is perceptible. This lamp takes 397 watts with seventy volts impressed and a current of 6.6 amperes. It shows a power factor of .86. The mean hemispherical intensity is 314; that is to say, it gives nearly the same light below the horizontal as does the direct-current lamp provided with clear outer globe and no shade. The

efficiency is 1.26 watts per mean hemispherical Hefner unit. As producers of light below the horizontal,

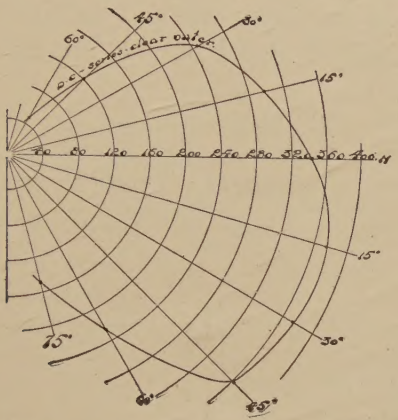

FIG. 15.—LAMP 67—DIRECT-CURRENT SERIES INCLOSED-ARC, CLEAR OUTER AND OPALESCENT INNER GLOBES

the two lamps equipped in the manner stated are about equally efficient, but the direct-current lamp

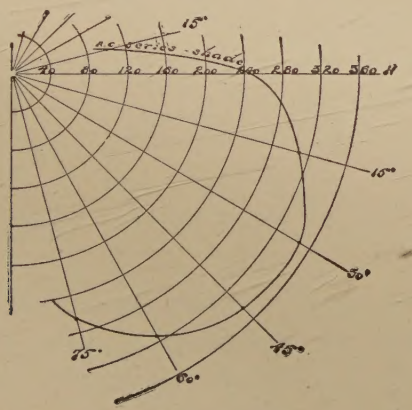

FIG. 16.—LAMP 268—ALTERNATING-CURRENT SERIES INCLOSED-ARC, OPALESCENT INNER GLOBE AND METALLIC REFLECTOR

would, of course, be considerably superior if fitted with a shade instead of a clear outer globe.

I wish to acknowledge the very efficient services of my assistant, Mr. Paul B. Sawyer. He has not only worked faithfully in taking measurements and in constructing apparatus, but he

TABLE XIV

A. C. SERIES SHADE OPALESCENT INNER

LAMP 268

Angle	Intensity
75° A	
60° A	
45° A	
30° A	
15° A	98 H. U.
Hor.	253 "
15° B	310 "
30° B	352 "
45° B	348 "
60° B	319 "
75° B	267 "

Globes	Clear Outer Opalescent Inner
E. M. F.	70 volts
Current	6.6 amperes
Apparent watts	462.
Watts	397.
Power factor	.86
Mean hemispherical intensity, H. U.	314.
Watts per mean hemispherical, H. U.	1.26

has offered, from time to time, suggestions of value. I have also had the assistance of two members of the Senior Class at Purdue University: Messrs. P. G. Winter and G. F. Hardwicke.

Respectfully submitted,

C. P. MATTHEWS,